DOCUMENT RESUME

ED 162 826 SE 025 023

AUTHOR	Clarkson, W. W.; And Others
TITLE	Land Application of Wastes: An Educational Program. Pathogens - Module 9.
INSTITUTION	State Univ. of New York, Ithaca. Coll. of Agriculture and Life Sciences at Cornell Univ.
SPONS AGENCY	Corps of Engineers, Washington, D.C.; Environmental Protection Agency, Washington, D. C.
PUB DATE	Jan 78
GRANT	EPA-T-900500
NOTE	88p.; For related documents, see SE 025 014-035; Not available in hard copy due to copyright restrictions
AVAILABLE FROM	Van Nostrand Reinhold, 450 West 33rd Street, New York, N.Y. 10001
EDRS PRICE	MF-$0.83 Plus Postage. HC Not Available from EDRS.
DESCRIPTORS	*Disease Control; Environment; *Health; *Instructional Materials; *Land Use; *Learning Modules; Microbiology; Pathology; Postsecondary Education; Sanitation; *Waste Disposal; Wastes
IDENTIFIERS	Land Application; *Waste Water Treatment

ABSTRACT

This module is intended to help engineers evaluate the relative health risks from pathogens at land treatment sites versus conventional waste treatment systems. Among the topics considered are the following: (1) the relationship between survival time of pathogens and the chance of disease transmission to humans; (2) the factors that favor survival of pathogens in the soil; (3) survival of pathogens on vegetation; (4) factors which affect the movement of pathogens through the soil and their uptake and retention on soil particles; (5) the possibility of pathogens moving to the groundwater and how long they live in groundwater; (6) the risks of crop contamination and how to minimize them; (7) the effects of various conventional treatment processes on pathogen removal; (8) factors that affect efficiency of chlorination on pathogen removal; (9) ways to minimize disease risks to animals grazing on wastewater-irrigated pasture; (10) insect control at the land site; (11) specific pathogens contained in wastewater; (12) infective doses; and (13) ways to reduce pathogens in aerosols. (Author/BB)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED162826

Land Application of Wastes

An Educational Program

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY
J. D. Novak and
Van Nostrand Reinhold
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) AND USERS OF THE ERIC SYSTEM."

CORNELL UNIVERSITY
New York State College of
Agriculture and Life Sciences
A Statutory College of the State University
Ithaca, New York

PATHOGENS

Module 9

January, 1978

SE 025 023

LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

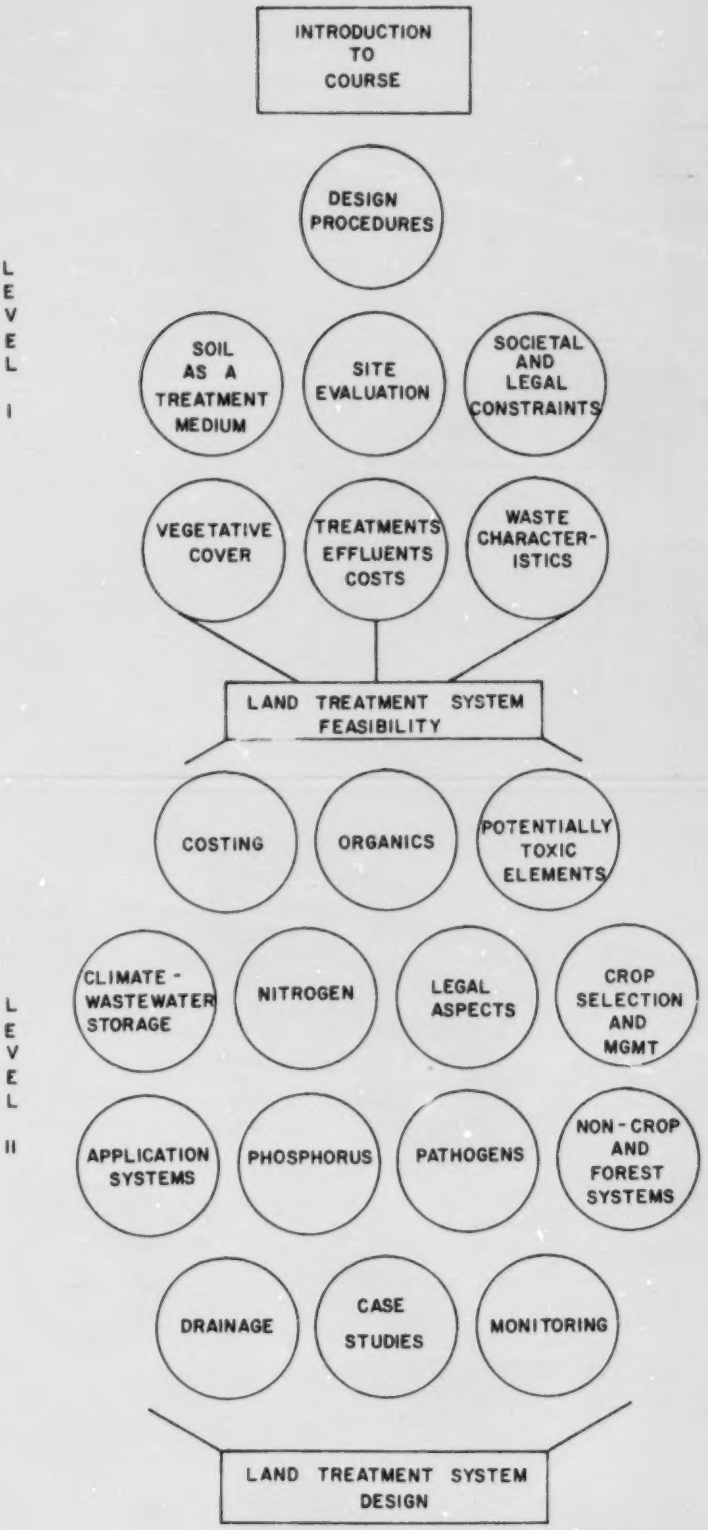
The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

Questions about the Program can be directed to:

Environmental Studies Program
NYS College of Agriculture and
Life Sciences
Riley-Robb Hall
Cornell University
Ithaca, NY 14853

Telephone (607) 256-2008



All rights reserved. No portion of this material may be reproduced without permission of the authors. Cost of the copy is reimbursement for reproduction only. Use of these materials is permitted only for courses authorized by the authors, the Environmental Protection Agency or the U.S. Army Corps of Engineers.

"From LAND APPLICATION OF WASTES, Vols. 1 and 2, edited by J. D. Novak
© 1979 by Litton Educational Publishing, Inc.
Reprinted by permission of Van Nostrand Reinhold Company."

PATHOGENS

Module 9

January, 1978

Summary

This module is intended to help engineers evaluate the relative health risks from pathogens at land treatment sites versus conventional waste treatment systems. It is recognized that more research is needed on the relative risks of the two systems. It should be stressed that conventional systems, such as trickling filters, may pose similar problems of possible disease spread. The engineer must consider the infective dose of various pathogens and the ultimate use of the wastewater being applied to the land.

This module examines the following topics:

--the relationship between survival time of pathogens and the chance of disease transmission to humans
--factors that favor survival of pathogens in the soil
--survival of pathogens on vegetation
--factors which affect the movement of pathogens through the soil and their uptake and retention on soil particles
--the possibility of pathogens moving to the groundwater and how long they live in groundwater
--the risks of crop contamination and how to minimize them
--effects of various conventional treatment processes on pathogen removal
--factors that affect efficiency of chlorination on pathogen removal
--ways to minimize disease risks to animals grazing on wastewater-irrigated pasture
--insect control at the land treatment site
--specific pathogens contained in wastewater, including most common bacteria, viruses, protozoa and worms
--infective doses of various pathogens
--ways to reduce pathogens in aerosols
--factors that influence the survival and dispersion of pathogens in aerosols
--summary of field tests on spread of pathogens via aerosols
--epidemiological study of disease spread from a land treatment site

Table of Contents

	Page
Summary	i
List of Figures	iv
List of Tables	v
Glossary	vi
Objectives	ix
I. Introduction	1
II. Pathogen Survival	4
A. Soil	6
B. Vegetation	9
C. Viruses	10
D. Movement and Retention of Pathogens in the Soil	11
1. Field Studies	14
2. Chemical Effects	15
3. Rainfall and Site Management	16
4. Virus Movement	17
E. Groundwater	20
III. Crop Contamination	21
A. Crops	21
B. Livestock	22
C. Onsite Workers	23
D. Insect Control	25
IV. Common Pathogens and Diseases	26
A. Bacteria	27
B. Viruses	29
C. Protozoas and Worms	31
V. Treatment Methods	32
A. Conventional Treatment Efficiencies	33
1. Chlorination	38
VI. Aerosols	39
A. Pathogen Survival	41
B. Aerosol Dispersion	43
VII. Epidemiology	44
VIII. Bibliography	46

		Page
IX.	Appendix	52
	1. Governmental Guidlines, Recommendations	53
	a. British Columbia	54
	b. California	60
	c. National Technical Advisory Committee on Water Quality	72
	2. Summary of Agricultural Research Recommendations	73

List of Figures

Figures		Page
1.	Barriers to disease transmission in land application sites	5
2.	Fecal coliform and streptococci dieback curves in soils	6
3.	Treatment processes differ in their removal of bacteria	34
4.	Less certainty exists on virus removal	35
5.	Protozoan removal data are very scarce	36
6.	Primary treatment appears more efficient for helminth removal	37

List of Tables

Tables		Page
1.	Survival of selected pathogens on soils	7
2.	Factors affecting enteric bacteria survival in soil	9
3.	Factors promoting virus removal from soil	10
4.	Factors influencing movement of virus in soil	20
5.	Survival of selected pathogens on vegetation	21
6.	Estimated concentrations of selected wastewater pathogens	33
7.	Factors affecting the efficiency of chlorine	38
8.	Factors affecting survival of bacteria and viruses in aerosols	42

Glossary

aerosol - a gaseous suspension of ultramicroscopic particles of a liquid; particles are in the size range of 0.01 to 50 micrometers (μm).

bacteria - any of numerous unicellular microorganisms traditionally classified with fungi as Schizomycetes. Bacteria occur in a wide variety of forms, existing either as free-living organisms or as parasites, and having a wide range of biochemical, often pathogenic, properties.

coliform bacteria - colon bacilli, or forms which resemble or are related to them. The coliform group of bacteria possess the faculty of fermenting lactose and milk sugar to produce gas, and therefore, can be simply diagnosed as being present by a simple visual observation. The major reason for the common use of coliform analysis in pollution control and water supply regulations is the simplicity of the test and the universal acceptance of a standard procedure.

cyst - a sac with a distinct wall. Many microorganisms form cysts under adverse environmental conditions. These cysts may contain either the egg, the immature organism, or the mature organism. Some pathogens are transmitted primarily by being released as cysts which are then ingested by the new host.

enteric - of or within the intestine. Enteric bacteria are microorganisms found in the intestinal tract of humans and animals.

epidemic - a sudden increase in the incidence rate of a disease to a value above normal, affecting large numbers of people and spread over a wide area.

epidemiology - the study of the mass aspects of disease.

fecal coliforms - the type of coliform present in virtually all fecal material produced by mammals. One of the common kinds of fecal coliforms is Escherichia coli (E. coli). Non-fecal coliforms originate in soil, grain, and decaying vegetation. Since the coliforms may not be pathogens, they only serve to indicate the potential presence of human disease organisms.

Glossary (cont'd.)

gastroenteritis - inflammation of the mucous membrane of the stomach and intestine, one form of which is called food poisoning. This disease may be caused by organisms which are contained in human wastes and are transmitted by ingestion of contaminated food or water.

helminth and helminth ova - a worm, especially a parasitic intestinal nematode or trematode worm. There are two phyla of helminths, the flatworms and the roundworms. Among the flatworms are the fluke and the tapeworm. Among the roundworms are the intestinal roundworm and the hookworm. The helminth ova or eggs are of particular interest to sanitary engineers because it is often the ova which must be eliminated from sewage. For instance, helminth ova are quite resistant to chlorination; they must be retained in anaerobic digesters for one month to ensure destruction; they can remain viable in sludge following primary treatment. The ova can be passed out with the feces of infected organisms and then ingested with food or water. One helminth ovum is capable of hatching and growing when ingested.

indicator organism - an organism that when measured in water indicates pollution or the presence of pathogens but which does not necessarily cause disease in itself. For instance, the presence of coliforms in water indicates that human disease organisms may be present, but coliforms themselves are not usually pathogens.

pathogen - a disease-producing agent, usually refers to living organisms.

protozoa - single-celled, usually microscopic organisms of the phylum or subkingdom Protozoa, which includes the most primitive forms of animal life. Few protozoa cause disease in man. The most common protozoan of interest to waste management personnel is Entamoeba histolytica, which causes amoebic dysentery. E. histolytica cannot exist in its active form outside of its host, but is capable of forming cysts which are excreted and may resist waste treatment processes.

vector - an agent, such as an insect, capable of mechanically or biologically transferring a pathogen from one organism to another. A mosquito which carries organisms that cause malaria is such a vector.

Glossary (cont'd.)

virus - a large group of infectious agents ranging in size from 10 to 250 namometers in diameter, composed of a protein sheath surrounding a nucleic acid core and capable of infecting all animals, plants, and bacteria; having the ability only to replicate inside a living cell. Characterized by total dependence on living cells for reproduction and by lack of independent metabolism.

Objectives

Upon completion of this module, the participant should be able to:

1. List four major types of organisms commonly found in wastewater which may be pathogenic.

2. Name potential means of pathogen spread shared by land application and conventional biological treatment plants.

3. Discuss the factors affecting survival of the various pathogens in soil.

4. Discuss what is known about pathogen removals in conventional treatment processes. Factors to be considered are:

    a. reliability of removal
    b. percent removal of each pathogen by each treatment process

5. Discuss factors affecting movement of microorganisms through soil.

6. Name two types of underlying rock which are undesirable due to ease of pathogen movement to groundwater. Name the physical property they have in common which facilitates the movement.

7. Define "infective dose" and compare the infective dose for typical organisms in each of the four groups of pathogens.

8. Summarize what is known about pathogen survival in aerosols. Include the percentage of the wastewater aerosolized by spray, survival times, distance of travel, and effect of chlorination vs. atmospheric desiccation on bacterial survival. List several methods of controlling aerosol transport of microorganisms.

Introduction

Several factors affect the perceived and actual public health problems posed by the land application of wastes. Land treatment must be compared equitably to conventional wastewater treatment systems in facilities planning. This makes it necessary to evaluate the relative health risks associated with land treatment and conventional waste treatment and disposal systems. This is a difficult task due to the wide range of parameters that may influence these risks. Much more research is needed in this area.

Health risks from land treatment must be compared to those from conventional treatment.

An important consideration is how the community views the system. Conventional systems, such as trickling filters, may pose similar, if less obvious, problems of possible disease spread. Sufficient data are not available to show whether or not land treatment is a greater health hazard than conventional treatment and discharge systems. The paucity of information available on disease caused by wastewater treatment processes may reflect:

--the absence of a problem,

--lack of intensive surveillance, or

--insensitivity of present epidemiological tools to detect recurrent small-scale incidence of disease.

The general health of the community is important in that if a disease is not present in the population, it will not be present in the population's wastes. Since the level of enteric disease in the United States is relatively low, wastewater in the U.S. would be expected to contain low levels of pathogens compared with that in many regions of Asia, Africa, and South America. However, the continual occurrence of waterborne disease outbreaks caused by sewage-contaminated water in the United States indicates that sufficient numbers of pathogens are present to be

General health of community is important in determining risk of disease from sewage.

a public health concern. Precautions must be taken even in the healthiest of communities as some persons are capable of transmitting disease, while not themselves exhibiting the disease. Typhoid Mary is perhaps the best known example of this phenomenon.

Because there is always a danger of pathogens in sewage, varying degrees of treatment are used to lessen the probability that viable pathogens will be released to the environment in concentrations large enough to cause disease. The major groups of pathogens vary in their resistance to sewage treatment processes.

Waterborne diseases persist in the United States, giving evidence of potential danger of pathogens in sewage.

It must be accepted that some pathogens remain viable after waste treatment. If the wastes are applied to the land, then pathogens may be present on the soil and vegetation. However, the probability of these pathogens causing health problems is quite low. No epidemics related to land application of treated, disinfected sewage have been reported (Dunlop, 1968).

It should be emphasized, too, that no incidents of disease have been documented from any planned and properly operated land treatment system in the United States. Comparative epidemiological studies on human populations associated with conventional as well as land treatment systems are needed to provide sufficient and reliable data on which uniform regulations can be based.

No disease transmission has been documented from any planned, properly operated land treatment system in the U.S.

Thus, evaluation of potential health hazards must rest upon our knowledge of the occurrence of pathogens in wastewater and their fate during land treatment.

If the wastewater is to be used to irrigate a crop, several precautions should be taken. Most states in the United States have their own regula-

Most states regulate irrigation of crops with wastewater to prevent disease transmission.

tions which must be observed, or guidelines which are not legally binding, but strongly suggested. Below are several which are broadly applicable.

- -Raw wastewater should not be used for irrigation.
- -Raw wastewater may only be used to irrigate nonedible or orchard crops (without spray application).
- -Total coliform density should not exceed 5000 MPN organisms/100 ml for most irrigation water uses.
- -Crops to be eaten raw should not be irrigated with wastewater unless the MPN is low.
- -Livestock feed crops should be dried and stored to reduce possibility of pathogen transmittal.

These are all examples of attempts by various state regulatory bodies to interpret and put into effect information such as that presented in this module.

The ultimate use of the wastewater applied to land is also of concern in terms of pathogen content. If the water is to be reclaimed for drinking water, additional precautions such as chlorination may be necessary. At present, this is not looked on favorably by a majority of workers in the field. In emergencies, reuse of wastewater for drinking can be a viable alternative (Bernarde, 1973). In most cases, however, the water will eventually recharge the groundwater. Movement of pathogens to groundwater is generally quite restricted. Many pathogens are filtered from the percolating water at or near the soil surface.

The ultimate use of wastewater will determine how much its pathogenic content must be reduced.

Movement of pathogens to the groundwater is generally restricted in land application systems.

Different groups of pathogens need different environmental conditions to remain active. A

bacterium may remain alive in a dry soil only 2 days, while a helminth egg, protected by its cyst, can remain viable for months or even years under drought conditions.

There are two concerns which the engineer must face in terms of pathogens applied to land. First, there is the real threat - the actual possibility of disease transmission to the human community involved in applying sewage that is treated to varying degrees to the land. A much more difficult problem is in quantifying the degree of danger that may result, and in satisfying the public that the danger has been minimized.

No treatment process can eliminate 100% of the pathogens. The difficulty lies in quantifying the risk to the public and convincing them that risk has been minimized.

The literature reveals few epidemic outbreaks related to wastewater irrigation. Where these have occurred, they were most often caused by application of raw, untreated sewage to foods eaten raw (Bryan, 1974). Secondly. although many studies have revealed possible or potential hazards, none have claimed a means to eliminate 100% of the pathogens in wastes. Therefore, we must assume that we are working with a possible source of disease.

Much material in this section has been adapted from the EPA Process Design Manual on land application systems, Appendix D, "Pathogens" (1977).

Survival Time Relates to Chance of Transmission

The engineer must understand the persistence and movement of pathogens in the soil, in overland runoff, in the groundwater, on crops, and in aerosols in order to control their spread to humans and animals following land application of wastewater.

The survival of pathogens in soil contributes to the chance of pathogen transfer to a susceptible host, for those microorganisms not intercepted

before reaching the soil. It has generally been found that land treatment using intermittent application and drying periods results in die-off of enteric bacteria retained in the soil.

Chances of disease transmission are greater the longer pathogens survive in the soil because they are more likely to be transferred to a susceptible host.

There are several ways pathogens may be spread when applied to land. They may be enclosed in a droplet of water and spread as aerosols. Bacteria and viruses, due to their small size, are particularly susceptible to being spread as aerosols. Helminth ova and protozoan cysts may become imbedded in the soil where they can remain viable if environmental conditions are conducive. Or, pathogens may be spread to vegetation and can cause disease upon ingestion. Pathogens do not necessarily stay in one place, but tend to travel with water movement through the system.

Pathogens must overcome many barriers to transmit disease following land treatment.

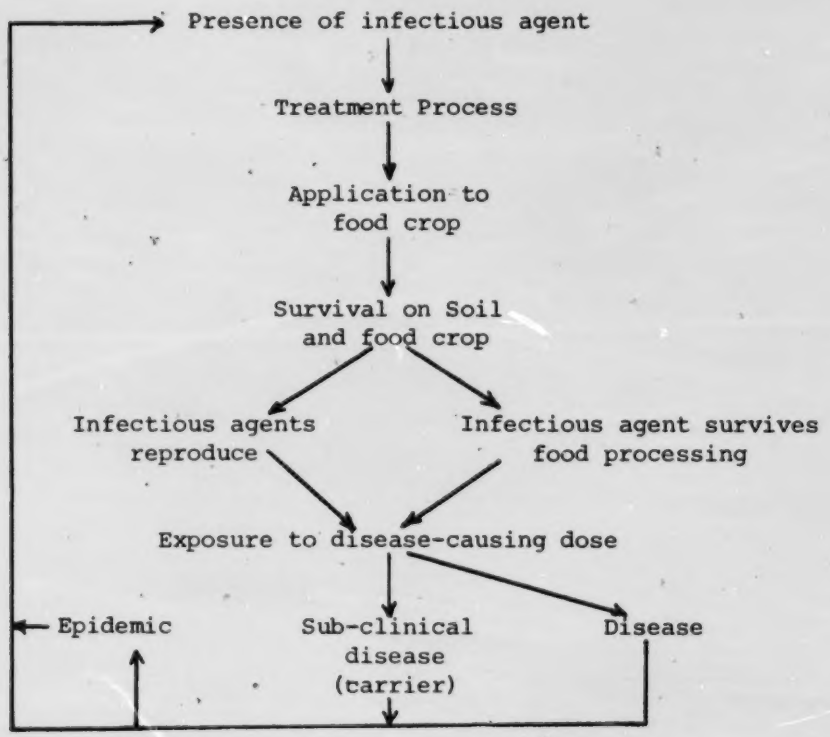


FIGURE 1. Pathogens must overcome several barriers in order to result in disease transmission from infectious agent to healthy populations via land application of wastes.

Pathogens can survive in soil: Factors that favor the survival of native soil organisms tend to be destructive to pathogens in the soil. The native organisms, adapted to the soil environment, can eliminate the pathogens by competing with them for food and living space.

Many pathogens are destroyed by the natural environmental conditions which favor native soil organisms.

The chance of sewage-borne pathogens moving through the soil to the groundwater, or off the site in surface runoff, depends partially on how long the pathogens survive in the soil. Initial reactions between pathogens in wastewater and the soil matrix are physical entrapment and chemical adsorption at the soil surface. Bacterial pathogens appear to undergo rapid die-off in the soil matrix. The data presented in Figure 2 are typical of this die-off (Miller, 1973). However, these curves are not applicable to all species of bacteria in all situations. For example, Rudolfs, et al. (1950) found fecal streptococci from digested sewage sludge to survive up to six months in clay soil, though not in silt loam or sandy soil.

Some pathogens are physically entrapped and chemically adsorbed at the soil surface, undergoing rapid die-off in the soil matrix.

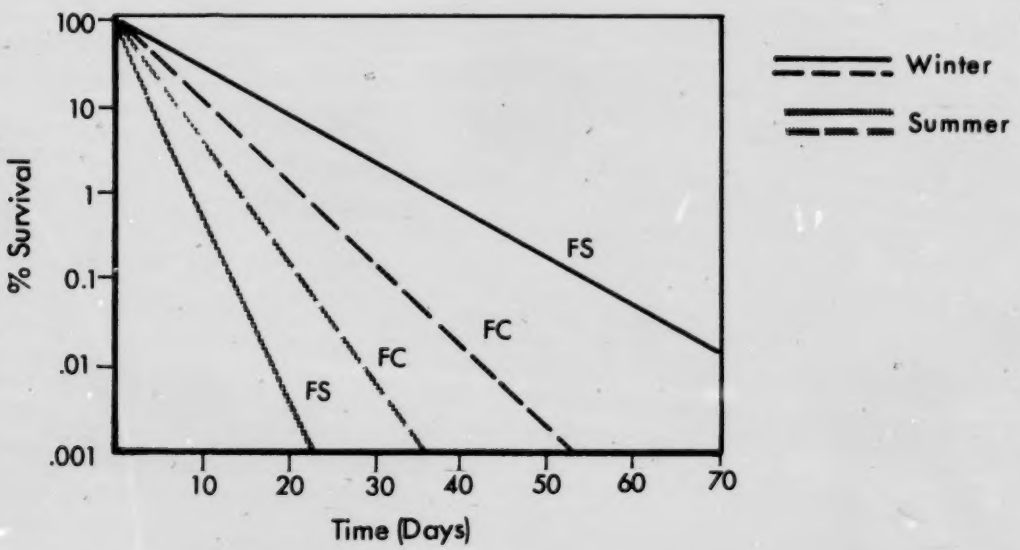


Figure 2
Fecal Coliform (FC) and Fecal Streptococci (FS) Show Typical Dieback Curves for Bacteria in Soils (from Von Donsel, in Miller, 1973).

In general, bacteria may survive in the soil for a period varying from a few hours to several months, depending on the type of organism, type of soil, moisture-retaining capacity of soil, moisture and organic content of wastewater being applied, and predation and antagonism from the resident microbial flora of the soil. The key to eliminating pathogens from soil appears to lie in ensuring adequate detention time in the soil for the pathogens to be destroyed by the above factors. Soils which are very coarse-textured are often not very effective in eliminating pathogens, as the pathogens pass too quickly through the soil matrix.

Pathogen destruction is usually enhanced if pathogens are detained long enough in the soil matrix.

Enteric bacteria in reduced numbers usually persist in the soil for 2 to 3 months, although survival times as long as 5 years have been reported. (Rudolfs, et al., 1950) Under certain favorable conditions, applied organisms may actually multiply and increase in numbers. But most pathogenic bacteria cannot reproduce in the soil and will slowly die off. Table 1 lists typical survival times for certain pathogens.

Most pathogenic bacteria cannot reproduce in soil and slowly die off.

TABLE 1. Survival of Selected Pathogens on Soils (Parsons, et al., 1975)

Organism	Range of Survival Time
Salmonella	15 - more than 280 days
Salmonella typhi	1 - 120 days
Tubercle bacilli	more than 180 days
Entamoeba histolytica cysts	6 - 8 days
Enteroviruses	8 days
Ascaris ova	Up to 7 years
Hookworm larvae	42 days

The influence of soil type on bacterial survival is important insofar as its moisture content, moisture-retaining capacity, pH, and organic matter content are concerned.

Soil moisture, pH, and organic matter content all have an effect on bacterial survival.

The survival of E. coli, S. typhi, and M. avium is greatly enhanced in moist rather than in dry soil. Survival time is less in sandy soil than in soils with greater water-holding capacity, such as moist loam and muck. Survival time is shorter in strongly acid peat soil (pH 2.9 to 3.7) than in limestone soil (pH 5.8 to 7.7). Increasing the pH of peat soil has resulted in extended survival of enterococci. The effect of higher soil pH on bacterial persistence is often ascribed to an increased availability of nutrients or to an effect on inhibitory agents.

Bacteria survive longer as the organic content of the soil increases. Salmonella declined rapidly when they were applied to pastures with water containing no fecal matter, as compared to wastewater contaminated with feces (Tannock and Smith, 1971). Under natural conditions, the buildup of organisms may be greater in soils with high moisture and high organic content.

Pathogens survive longer in winter than in summer because the self-cleansing properties of the soil are slowed down.

Both pathogens and indicator organisms survive longer in winter than in summer. S. typhi survived as long as 2 years at constant freezing temperatures in one study. In fact, the self-cleansing property of soil is slowed down in the Russian Arctic where winters are prolonged (Mirzoev, 1968). Microorganisms disappear more rapidly at the soil surface than below the surface, apparently because of desiccation, effects of sunlight, and other factors at work at the soil surface.

The competition and antagonism the alien enteric bacteria face from the resident soil microflora is another important factor. Organisms applied to sterilized soil survive longer than they would in

unsterilized soil. Table 2 lists factors that influence the survival of bacteria in soil.

TABLE 2. Factors that Affect the Survival of Enteric Bacteria in Soil (Metcalf and Eddy, 1977)

Factor	Remarks
pH	Shorter survival in acid soils (pH 3 to 5) than in neutral and alkaline soils
Antagonism from soil microflora	Increases survival time in sterile soil
Moisture Content	Longer survival in moist soils and during periods of high rainfall
Temperature	Longer survival at low (winter) temperatures
Sunlight	Shorter survival at the soil surface
Organic matter	Longer survival (regrowth of some bacteria when sufficient amounts of organic matter are present)

Pathogens Survive for Shorter Times on Vegetation

Vegetation irrigated with wastewater is likely to have a varying number of pathogens associated with it. This is true even if the wastewater has received pretreatment, since, as has been seen, primary and secondary treatment processes do not eliminate all the pathogens.

In some cases, large numbers of pathogens, particularly protozoan cysts and helminth eggs, may remain viable after treatment. No state which has developed guidelines for land application of wastes allows vegetables or fruits which are to be eaten raw to be spray-irrigated with wastewater. California does allow soil surface irrigation of fruit orchards with primary effluent, however, because fruit does not contact the wastewater. These and other

Wastewater pathogens don't generally survive as long on vegetation as they do in soil because they're more exposed to adverse environmental conditions.

regulations promulgated by the states to control land application of wastes are reviewed in Module 16 "Legal Aspects."

In general, pathogens survive for shorter periods on vegetation than in soil. This is due to the lack of protection given by vegetation from ultraviolet radiation, dessication, and temperature extremes. Coliform bacteria may survive up to 35 days on vegetation, Salmonella typhi up to 68, and tubercle bacilli up to 49 days on grass, if they can adhere to the underside of plant parts where they are protected from direct sunlight.

Information Sketchy on Virus Survival

There is little information available on the survival of enteric viruses in the soil, on crops, or in the groundwater. The little available information is limited to only a few types of viruses. There is no information on the survival of viruses in aerosols generated by sprinkler irrigation of wastewater or aeration tanks and trickling filters.

Information on the survival of enteric viruses in soil, on crops, in groundwater is limited to a few types of virus.

TABLE 3. Several Factors Promote Virus Removal from Soil (Sproul, 1975)

Type of subsoil	Most desirable - deep Adequate - sandy soils; require greater depth for removal No removal - fractured layers
Soil depth	At least 5 to 10 feet to ledge or fragipan
Depth to groundwater	At least 5 feet
Application rate	Maximum rate of 0.05 to 0.10 feet per day (.6 to 1.2 inches)
Water quality	As clean as possible
Adsorption characteristics of viruses	No control possible

Available information on virus survival is summarized below:

--Virus survival in soil depends on the nature of the soil, temperature, pH, moisture, and possibly antagonism from soil microflora.

--Viruses readily adsorb to soil particles. Such viruses bound to solids are as infectious as free viruses.

--Viruses survive for times as short as 7 days and as long as 6 months in soil. Climatic conditions, particularly temperature, have a major effect on survival time.

--Enteric viruses can survive from 2 to more than 188 days in fresh water, temperature being the most important factor with survival greater at lower temperatures.

Heat and sunlight are believed to kill viruses.

--Virus survival on crops is shorter than in soil, because viruses are more exposed to deleterious environmental effects.

--Contamination of crops most commonly occurs when wastewater comes into contact with the surface of the crop.

--In rare cases, the translocation of animal viruses from roots of the plants to the aerial parts can occur.

--Sunlight is believed to be a major factor in killing viruses.

--Viruses cannot reproduce at all in the soil, and they slowly die off.

Soil Movement/Retention Relates to Treatment Efficiency

Retention time in the soil must be related to survival time to determine the probability of some concentration of viable bacteria and viruses passing through to the groundwater. This can be thought of as a treatment efficiency of microbial removal by the land treatment system.

The longer pathogens are retained in the soil, the more die off and the chance of their contaminating the groundwater is reduced.

Before assessing the movement and retention

characteristics of microorganisms in the soil, all the inactivation mechanisms in effect prior to infiltration of wastewater to the soil must be taken into account. This includes die-off in holding ponds and on the surface of the ground and crop due to sunlight and desiccation. Desiccation in aerosol droplets from spray systems is minor because of the very small fraction of the applied wastewater which is aerosolized (<1.0%).

Once the relative level of microorganisms surviving to infiltrate is determined, the mechanism acting on them must be evaluated to estimate the treatment efficiency. A discussion of the various forces acting to retain or facilitate the movement of microorganisms through soil follows.

Filtration by the soil at the soil-water interface is the primary way bacteria are removed from wastewater and retained in the soil.

Most bacteria are subject to filtration by the soil at the soil-water interface. Heavy-textured clays and consolidated sands are the most efficient soils for filtration. As a result of mechanical and biological straining, and the accumulation of wastewater solids and bacterial slimes, an organic mat is formed in the top 0.2 in. (0.5 cm) of soil. This mat is capable of removing even finer particles by bridging or sedimentation before they reach and clog the original soil surface. Butler et al. (1954) observed the greatest removal of bacteria on the mat that formed on the soil surface, followed by a subsequent buildup of bacteria at lower levels. Although filtration by the soil and, in some cases, an additional biological mat is the primary means of retaining bacteria in the soil, other forces also act on them.

Wastewater bacteria are effectively removed by percolation through a few feet of fine soil by the process of straining at the soil surface and at intergrain contacts, sedimentation, and adsorption by

soil particles. Adsorption of bacteria to sand depends on pH and zeta potential of the soil and is reversible. Factors that reduce the repulsive forces between the two surfaces, such as the presence of cations, would be expected to allow closer interaction between them and allow adsorption to proceed.

Other mechanisms that retain bacteria in the top few feet of fine soil are intergrain contacts, sedimentation and adsorption by soil particles.

Adsorption plays an important role in the removal of microorganisms, as well as other wastewater constituents, in soils containing clay because of the very small size of clays, their generally platy shapes, and the occurrence of a large surface area per given volume. The substitution of lower valence metal atoms in their crystal lattices make them ideal adsorption sites for bacteria in soils. (Krone, 1968) Filtration effects predominate in sandy soils due to their granular structure.

Soils containing clay remove most microorganisms through adsorption. Soils containing sand remove them through filtration at soil-water interface.

It is apparent from the foregoing discussion that the upper layers of the soil are most efficient for removing microorganisms. Once these organisms are retained, the primary consideration is the length of their survival in the soil matrix, where they are inactivated following exposure to sunlight, oxidation, desiccation, and antagonism from the soil microbial population.

Upper layers of soil are most efficient for removing microorganisms from wastewater.

Other complex and interlocking factors determine the distance of travel. Generalizations are difficult, but movement is related directly to the hydraulic infiltration rate and inversely to the particle size of the soil and to the concentration and cationic composition of the solute. Retention and subsequent survival also depend on the rate of groundwater flow, oxygen tension, temperature, and availability of food. Krone et al. (1958) developed mathematical equations to predict movement based on size, shape, density, viscosity of the liquid, soil type, surface characteristics, the process of filtration, and physical and bio-

Movement of microorganisms through soil relates directly to hydraulic infiltration rate and inversely to the size of soil particles and the concentration and composition of cations in the solute.

logical characteristics of the pathogens, including their size, shape, surface properties, and die-off rates. One point that must not be overlooked is that any microorganism will travel quickly through any fissured underlying zone such as limestones or basalts. This condition should be avoided if the potential for groundwater contamination is deemed significant by a high application concentration, lack of significant retention time in the overlying soil matrix, or evidence that rapidly moving groundwater passing under the site will be tapped for drinking water nearby.

Microorganisms will travel quickly through fissured zones such as limestone and basalt to the groundwater.

The first major field studies on bacteria removal during wastewater percolation through soil were performed at Whittier and Azusa, California. At Whittier, coliform concentrations were reduced from 110,000/100 mℓ to 40,000/100 mℓ after percolation through 3 ft (0.9 m) of soil in 12 days, and none appeared at greater depths. When treated wastewater effluent containing 120,000 organisms/100 mℓ was allowed to percolate in Azusa soil, the percolates produced at 2.5 and 7 ft (0.75 and 2.1 m) contained 6,000 organisms/100 mℓ (MeGauhey and Krone, 1967). At Lodi, California, coliform levels were observed to decrease below drinking water standards within 7 ft (2.1 m) of the surface when wastewater effluent was applied to sandy loam soil, but in one case, coliforms were detected at a depth of 13 ft (3.9 m) (Gerba, et al., 1975).

Several full-scale, detailed studies have demonstrated the high bacterial removal that can be achieved by land treatment.

In a thorough study at the Santee Project near San Diego, California, impressive removal of indicator bacteria occurred within 200 ft (60 m) of horizontal travel; little additional removal occurred in the next 1,300 ft (396 m). The medium consisted of coarse gravel and sand confined in a river bed. At the Flushing Meadows Project near Phoenix, Arizona, wastewater was applied to

infiltration basins that consisted of 3 ft of fine loamy sand underlain by a succession of coarse sand and gravel layers to a depth of 250 ft (75 m). With a wastewater infiltration rate of 330 ft/yr (99 m/yr), the total coliforms decreased to a level of 0 to 200 organisms/100 mℓ at 30 ft (9 m) from the point of application when basins were inundated for 2 weeks followed by a dry period of 3 weeks. When 2- to 3-day inundation periods were used, however, the total coliform levels were reduced to 5/100 mℓ, a reduction of 99.9% (Gerba, et al., 1975).

Viruses are primarily removed from wastewater by adsorption by the soil; thus factors enhancing adsorption increase virus removal.

Unlike bacteria, where filtration at the soil-water interface appears to be the main factor in limiting movement through the soil, adsorption is probably the predominant factor in virus removal by soil. Thus, factors influencing adsorption phenomena will determine not only the efficiency of short-term virus retention but also the long-term behavior of viruses in the soil. Viruses tend to exhibit colloidal properties, and their attraction to soil particles is strongly influenced by pH of the soil, presence and concentration of cations, and the ionizable groups on the virus itself. pH and cationic effects are readily reversible, so once adsorption is achieved, a change in conditions can wash virus through the soil layer.

Virus adsorption is enhanced at pH below 7 and reduced at pH above 7. Since pH is changeable, once adsorption is achieved, a change can reverse it and viruses can be washed through the soil layer.

The pH is of considerable importance relative to adsorption. At the pH at which the isoelectric point of the virus occurs, the net electric charge is zero. The virus has a positive charge below the isoelectric point, and a negative charge above the isoelectric point. Viruses are strongly negatively-charged at high pH levels and strongly positively-charged at low pH levels. The isoelectric pH for enteric viruses is usually below pH 5; thus, in the pH range of most soils; enteroviruses as well as soil

particles retain a net negative charge. In general, virus adsorption to surfaces is enhanced at a pH below 7 and reduced at a pH above 7 (Wallis, et al., 1972). It is important to note that viruses once adsorbed to solids at a low pH are readily desorbed by a rise in pH.

The action of cations on viruses has been well documented, although the exact chemical mechanism at work has not been determined. The greater the positive charge of cations in solution with viruses, at a given concentration, the greater the attraction of the virus for clay soil particles. Studies on the effect of organic matter content of the soil on virus retention have produced conflicting results.

The greater the positive charge of cations in solution with viruses, the greater the attraction of viruses for clay particles.

Laboratory studies have indicated that rainfall can have a dramatic effect on the migration of viruses through soil. Alternating cycles of rainfall and effluent application result in ionic gradients that enhance the movement of virus. Rainfall acts to drop the ionic concentration of salts in the soil after wastewater application. Such changes in ionic strength have been found to be closely linked with the elution of viruses near the soil surface (Duboise, et al., 1976). This is seen as a burst of released viruses in soil columns when the specific conductance of the water in the soil column begins to decrease after the application of rainwater (simulated in the laboratory by the use of distilled water). This same elution effect can also be seen if a rise occurs in the pH of the water applied to the surface of the soil; that is, a rise in pH from 7.2 to 8 or 9 results in the elution of viruses adsorbed to soil. Viruses are also capable of elution even after remaining in columns saturated with wastewater for long periods of time.

Alternating cycles of heavy rainfall and effluent application decrease virus retention by the soil.

Studies have indicated that certain management practices may prove useful in limiting virus migration through soil (Lance, et al., 1976). Using 98 in. (250 cm) columns of sandy loam soil, they found that many of the viruses eluting near the soil surface after addition of 4 in. (10 cm) of distilled water were later adsorbed near the bottom of the column and that migration of the viruses could be minimized if the columns were flooded with wastewater shortly after the simulated rainfall. In addition, allowing the columns to drain (i.e., soil not saturated with effluent) for at least 5 days before application of the distilled water resulted in no apparent virus movement through the soil.. This led the authors to suggest that if a heavy rainfall occurred at a land treatment site within 5 days after application of wastewater, the area could be reflooded with wastewater to restrict subsurface virus migration through the soil. This could only be attempted if it fit in with other wastewater renovation parameters, and at this time, the practice of flooding a site to contain virus movement cannot be endorsed without qualifications.

Studies of virus movement suggest that reflooding a site with wastewater after a heavy rainfall is advantageous if wastewater had been applied within 5 days before the rainfall. Such a practice cannot be endorsed without considering other effects of such flooding.

Only recently have advances been made in the concentration and sampling of viruses from large volumes of water, enabling more precise field experiments on virus movement through soils to proceed. Therefore, very little lab work has been paralleled in full scale. There is some field data corroborating the foregoing theory of rainfall effects on virus movement.

Wellings et al. (1974) reported on the travel of viruses through soil at a wastewater reclamation pilot project near St. Petersburg, Florida. At a 10 acre (4 ha) site, chlorinated secondary effluent was applied by a sprinkler system at the rate of 2 to 11 in./wk (5 to 28 cm/wk). The

soil consisted of Immokalee sand with little or no silt or clay. On one side of the test plot, an underdrain of tiles was placed at a depth of 5 feet (1.5 m) on top of an organic impermeable layer. This subsurface drain directed the percolated water through a weir where gauze pads were placed for the collection of viruses. Both polioviruses and echoviruses were isolated from the weir water, demonstrating that viruses must survive aeration and sunlight during spraying as well as percolation through 5 feet (1.5 m) of sandy soil. Viruses were also isolated in wells 10 and 20 feet (3 and 6 m) below the soil surface when 50 to 150 gallons (189 to 567 L) of percolate were sampled. No viruses were detected in these wells for the first 5 months of study. Only after two heavy rains was poliovirus type 1 isolated. The viruses were first detected in the 10 foot (3 meter) well and some time later appeared in the 20 foot (6 m) well, indicating that viruses were migrating through the soil. The authors reasoned that the high rainfall resulted in a large increase in the water/soil ratio which led to increased solubility of portions of the organic layer and thus desorption of attached viruses. The observation of viruses as a "burst" after the rainfall was cited as evidence that the rainfall was responsible for the presence of viruses in the wells.

One study showed that heavy rainfall caused desorption of viruses because of increased solubility of organic layer. Viruses migrated through soil to contaminate a 20-foot well.

This same group of investigators (1975) also reported on the detection of viruses in groundwater after the discharge of secondary effluent into a cypress dome in Florida. The soil under the dome consisted of black muck and layers of sand and clay. Viruses were isolated from wells 10 feet (3 m) deep, again after periods of heavy rainfall. The viruses had traveled 23 feet (7 m) laterally subsurface to reach the observation wells. Another important observation made during this

study that is not generally recognized is the failure to detect fecal coliform bacteria in the well samples found to contain viruses.

One study detected viruses but no fecal coliform bacteria in well water; thus the presence or absence of fecal coliform does not always indicate the presence or absence of pathogens.

A virus study was conducted at a rapid infiltration site at Fort Devens, Massachusetts, where primary effluent was applied. High concentrations of viruses were added to the effluent. Virus travel through the coarse sand containing little clay and a low surface area was observed (Schaub et al. 1975).

In contrast to these findings, field studies at the Flushing Meadows rapid infiltration project near Phoenix, Arizona, indicate limited virus movement through the soil (Gilbert, et al., 1976). At this site, basins in sandy loam underlain at a 3 ft depth of coarse sand and gravel are intermittently flooded with secondary effluent at an average hydraulic loading rate of 300 ft/yr (90 m/yr). Although viruses were detected in the wastewater used to flood the basins, no viruses were detected in wells 20 ft. (6 m) deep, located midway between the basins. These results indicated that at least a 99.99% removal of viruses had occurred during travel of secondary treated wastewater through 30 ft. (9 m) of sandy soil--20 ft (6 m) vertically and 10 ft (3 m) laterally. The low rainfall, fine sandy loam, and the practice of intermittent flooding of the soil during land treatment at this site may have resulted in better conditions for virus removal than at other land treatment sites studied to date.

A land treatment site with low rainfall, fine sandy loam, and the practice of intermittent flooding with wastewater achieved a high percentage of virus removal.

Table 4 is a general summary of properties of land application sites relating to virus retention or movement in soil.

TABLE 4. Factors that Influence the Movement of Viruses in Soil

Factor	Remarks
Rainfall	Viruses retained near the soil surface may be eluted after a heavy rainfall because of the establishment of ionic gradients within the soil column.
pH	Low pH favors virus adsorption; high pH results in elution of adsorbed virus.
Soil composition	Viruses are readily adsorbed to clays under appropriate conditions and the higher the clay content of the soil, the greater the expected removal of virus. Sandy loam soils and other soils containing organic matter also are favorable for virus removal. Soils with a low surface area do not achieve good virus removal.
Flowrate	As the flowrate increases, virus removal declines, but flowrates as high as 32 ft/d (9.6 m/d) can result in 99.9% virus removal after travel through 8.2 ft (2.5 m) of sandy loam soil.
Soluble organics	Soluble organic matter competes with viruses for adsorption sites on the soil particles, resulting in decreased virus adsorption or even elution of an already adsorbed virus. Definitive information is still lacking for soil systems.
Cations	The presence of cations usually enhances the retention of viruses by soil. An increase in valence enhances retention.

Knowledge Limited on Groundwater Survival

Although more studies are needed, data show that bacteria may survive in groundwater for months.

If pathogenic organisms pass through coarse soil and fractured rocks like limestone, they may reach the groundwater. Although few studies have been made on bacterial survival in groundwater, it appears that bacteria may persist in underground water for months.

E. coli have been found to survive up to 1,000 days in subsoil water, whereas a 50 % reduction in numbers occurred within 12 hours in well water. It should be pointed out that there is wide variation in the reported length of bacterial viability in under-

ground waters, and more careful studies should be made before definite conclusions are drawn.

Crop Contamination Varies

In general, the extent of crop contamination can be determined by the type of crop and the kind of irrigation practice that is used. Wastewater irrigation of fiber crops presents the least health risk and that of food crops, especially those to be eaten raw, the greatest risk. Subsurface irrigation or certain flooding techniques avoid direct contact between wastewater and the vegetation, whereas sprinkling and flooding wet the low-growing vegetation as well as the soil. The greatest health concern is with low-growing crops, such as vegetables, which have a greater chance of contamination and are often eaten raw. Table 5 summarizes reported survival times for relatively common pathogenic organisms.

Subsurface irrigation and certain flooding techniques on food crops reduce the risk of crop contamination by wastewater.

TABLE 5. Survival of Selected Pathogens on Vegetation (Parsons, et al., 1975)

Organisms	Media	Survival Times (days)
Salmonella	Vegetables, fruits	3 - 49
	Grass or clover	12 - more than 42 (and over winter)
Tubercle bacilli	Grass	10 - 49
Entamoeba histolytica cysts	Vegetable	less than 1 - 3
Enteroviruses	Vegetables	8
Ascaris ova	Vegetables, fruits	27 -35

Disease Risk to Grazing Animals can be Minimized

Pathogens may be transmitted to animals grazing on pasture land recently irrigated with wastewater. Some state laws prohibit grazing on such areas while other state laws require that dairy animals not be allowed to graze on such areas for a certain number of days following irrigation.

Although a number of cases of disease in animals have been attributed to their unintentional exposure to wastewater, less is known about the risks to animals grazing on pastures irrigated with wastewater. Grazing land has been irrigated with untreated wastewater on a large scale in Europe and Australia and with treated wastewater in the United States. There seems to be little threat to the health of farm animals under normal conditions. It also appears that cattle which are fed effluent-irrigated forage or silage show no ill effects nor does the milk or meat from them appear to be infected.

The risk of transmitting disease to animals grazing on wastewater-irrigated pasture depends on how long pathogens persist, their concentration, the animals' health and the interval between irrigation and grazing.

However, diseases have been transmitted to domestic animals from sewage-contaminated water and pasture. Carefully controlled experiments and field data need to be conducted to develop effective guidelines in this area.

The chances of infection for animals grazing on wastewater-irrigated pasture depends on: the persistence of pathogens, the concentration of pathogens, the health of the animals, the interval between irrigation and grazing.

The disease threat to animals from eating wastewater-irrigated crops and fodder can be minimized by:

--Allowing animals to graze only after a certain interval of time has passed following irrigation. A number of pathogens in wastewater are inactivated during desiccation and when exposed to sunlight.

--Drying forage crops

--Storing the dried forage before feeding it to animals

Smart (in Parsons, et al. 1975) noted that there is little to indicate that feeding hay irrigated with sewage effluent to cattle poses a health hazard if the hay is baled when dry, and cured for 14 days. He also noted that there is no health hazard to humans from eating the meat of these animals.

Risks of infection among animals are not limited to Salmonella. Pseudomonas aeruginosa, Mycobacterium tuberculosis, and Leptospira organisms may exist in waste applied to pasture and may present a risk to the health of dairy cows and calves, but no documented evidence exists at present to indicate that a hazard exists. Calves that grazed pastures to which 10^6 S. dublin organisms/mℓ of slurry had been applied on the previous day became infected, but no infections resulted when the contamination rate was decreased to 10^3 organisms/mℓ of slurry (Taylor and Burrows, 1971). These limited results indicate that Salmonella may only be a concern in unusual circumstances when high concentrations of these organisms are present.

The diseases that may be transmitted from livestock to humans include tuberculosis(usually controlled by pasteurization of milk) scarlet fever, and influenza. Intestinal parasites and salmonellosis may be transmitted by humans eating the infected meat, and these infections may occur where sewage effluent is used for irrigation (Parsons, et al. 1975). Of course, any meat produced for human consumption on land application sites would be subject to the same inspection and health standards applicable to meat from any other source.

Precautions Decrease Occupational Risks

Workers handling wastewater are exposed more to pathogens than is the general public. The full

impact of this occupational risk has not been determined in epidemiological studies. More studies are needed to evaluate the hazard both to the worker and his contacts, however the following safeguards should be practiced. Employees of land treatment sites should:

Careful hygiene can minimize risk of disease to workers at land treatment sites.

--Receive regular typhoid and tetanus inoculations and poliovirus and adenovirus vaccinations

--Avoid direct contact with mists as much as possible; this is especially a problem at sprinkler irrigation sites.

--Change working clothes regularly to avoid not only personal infection, but the risk of spreading infection to the worker's family.

--Take care that their food and drinking water does not become contaminated by wastewater.

--Practice reasonable hygiene, such as washing hands after work and before meals.

Administering prophylactic doses of immune serum globulin to a worker who accidentally ingests wastewater should be considered. Immune serum globulin is prepared from large pools of normal adult plasma and gives passive protection in 80 to 90% of persons who have been exposed to infectious hepatitis within a period of one to two weeks.

Workers at conventional secondary treatment plants are also exposed to some continuous levels of enteric bacteria and viruses. Aerosol transport mechanisms disseminate microorganisms in trickling filter and activated sludge plants, as do such hands-on activities as bar screen cleaning and clearing of obstructions from mechanical gear. It is not felt that this exposure has presented any particular risk to these workers. A study some years ago in New York City showed that wastewater treatment plant workers had a lower rate of absenteeism than any other seg-

Exposure to pathogenic aerosols at conventional secondary treatment plants is not believed to put plant workers at any particular risk.

ment of the city's staff. This led some to propose a theory that the workers' proximity to continual low levels of pathogens had a beneficial effect by building their immunity to infectious diseases.

Insect Control Needed at Site

Control of mosquitoes at land treatment sites is needed to protect both the animal and human population from the nuisance and disease threat associated with large numbers of mosquitoes. Although there is no conclusive evidence that insect-transmitted disease increases in wastewater irrigation areas, more studies are needed to evaluate this problem.

Studies by Parizek, et al. (1967) did show, however, that the diversity and abundance of mosquitoes increases in areas where spray irrigation of wastewater is practiced. An increase in avian blood parasites which are transmitted by mosquitoes also was noted.

Control measures would include the avoidance of standing water conditions as much as possible, especially very shallow pockets of warm water remaining on the ground for more than a few days, since these pockets are favored breeding sites. Appropriate mosquito control efforts for land treatment systems would be the same as those practiced in any other area where standing water may occur, and local health authorities should be contacted for assistance as needed.

Because irrigation can increase the mosquito population at the site, control measures such as not letting water stand and other preventive approaches should be used.

Pathogens Common to Wastewaters, and the Diseases Which They Can Cause

Wastewaters Contain Pathogens

This part of Module 9 contains a discussion of the diseases which can be spread by improperly treated and handled sewage.

Although the general public may fear "disease" from a land treatment system, most persons are unaware of the specific diseases, the pathogens which cause them, and the degree of threat each poses to the community. The following sections provide a brief overview of the types of disease organisms which may be found in sewage, and a discussion of the most prevalent diseases associated with improperly handled sewage. A large variety of disease-causing microorganisms and parasites are present in domestic wastewater. These include pathogenic bacteria, viruses, protozoa, and parasitic worms. The number of individual species of pathogens is high. For example, over 100 different types of viruses are known to be excreted in human feces. The relative concentrations of these pathogens are highly variable, being dependent on a number of complex factors, but pathogens are almost always present in human wastes in sufficient numbers to be a public health concern.

A large variety of pathogens are present in domestic wastewater, posing a concern to public health.

The planner and engineer must:

--Identify and put into perspective any potential routes of disease transmission involved in land treatment of wastewater so that appropriate safeguards can be assured.

--Identify the relative risk of infection for humans and animals from these and other sources.

The engineer must identify routes of disease transmission and the risk of infection from these sources.

It should be noted that most of the studies cited in this section of the module involve applying untreated wastewater to the land in an unplanned

manner, or deliberate artificial seeding of bacteria or viruses in high concentrations to the soil to determine their survival or movement under various conditions. Each study had different objectives, types of soil, climatic factors, types of organisms, and methods of detection. Consequently, the results must be interpreted accordingly. Safeguards should be established on a case-by-case basis so that the relative risk of disease transmission in each situation can be evaluated individually.

Safeguards against disease transmission must be created on a case-by-case basis.

Bacteria Common to Wastewater

The most common bacterial pathogens found in wastewater include strains of Salmonella, Shigella, enteropathogenic Escherichia coli (E. coli), Vibrio, and Mycobacterium. The genus Salmonella includes over 1,200 different strains, many of which are pathogenic for both man and animals. Members of this group are commonly isolated from wastewater and polluted receiving waters.

The Salmonella bacteria are responsible for several diseases, including typhoid, paratyphoid, and salmonellosis. In all cases, disease is transmitted by fecal contamination of food or water. Salmonella typhosa has been responsible for incidents of typhoid fever associated with wastewater-contaminated drinking water and with the eating of raw vegetables grown on soil fertilized with untreated wastewater. Infected persons excrete the organisms in the feces and urine, thus posing the threat of rapid dissemination of the disease.

Typhoid, paratyphoid, and salmonellosis can be transmitted by fecal contamination of food or water.

Paratyphoid fever is caused by Salmonella bacteria other than Salmonella typhosa. The most common cause in the United States is S. schottmullerei. Although similar to typhoid fever, paratyphoid is milder and not as long-lasting. The infectious dose in man for S. typhi and S. schottmullerei is more than 100,000 organisms.

It takes 100,000 bacteria to infect a person with paratyphoid fever, a relatively high infectious dose.

Gastroenteritis, one form of food poisoning, may be caused by Salmonella typhimurium. The organism is excreted with feces, and is transmitted by ingestion of contaminated food or water. Many animals can be infected with Salmonella and may have these organisms in their meat, eggs, or feces. Rodents are among these, and should be controlled at land treatment sites.

The incidence of typhoid fever in the United States decreased markedly with widespread municipal water treatment in the early 1900's (N.Y. State Health Comm., 1932). However, the incidence of other Salmonella infections has increased. Although no cases of Salmonella infections directly related to land application sites have been reported, Salmonella diseases might be spread by land application of sewage if not properly handled.

Salmonella infections other than typhoid fever can be spread by land application of sewage if it is not properly handled.

Shigella organisms are the most commonly identified cause of acute bacterial diarrheal disease in the United States. These bacteria normally live in the intestinal tract of man. During the active disease, they are excreted in large numbers but remain viable in the feces only a short time. Waterborne spread of the organisms can cause outbreaks of shigellosis, commonly known as bacillary dysentery, which occur frequently in undeveloped countries and occasionally in developed countries. Unlike Salmonella, Shigella organisms are rarely found in animals other than man.

Controlling Shigella organisms includes proper sewage disposal and adequately-treated drinking water supplies. In addition, flies can transmit the disease, and therefore, must be controlled around the land treatment sites. Bacillary dysentery is a growing problem in Central and South America.

Proper sewage disposal and adequately treated drinking water control spread of Shigella, the most common cause of acute bacterial diarrhea in the U.S.

Cholera is caused by the organism Vibrio cholerae. In Israel in 1970 cases of cholera were attributed to the practice of irrigating vegetable crops with untreated wastewater. This practice is contrary to regulations of the Ministry of Health (Cohen, et al. 1971). There were no reported cases of cholera in the United States between 1911 and 1973, until a single case occurred in Texas with no known source. Although individual cases may arise in international travelers, they are unlikely to become a source of disease through wastewater land application projects.

Wastewater is unlikely to be a source of cholera pathogens.

Viruses are Smallest Pathogens

Viruses, the smallest wastewater pathogens, consist of a single nucleic acid surrounded by a protective protein coat. Viruses that are shed in fecal matter, referred to as enteric viruses, can infect tissues in the throat and gastrointestinal tract, but they are also capable of replicating in other organs of the body. They include the true enteroviruses (polio-, echo-, and coxsackieviruses), reoviruses, adenoviruses, rotaviruses, and infectious hepatitis virus.

Viruses, the smallest wastewater pathogen, cause diseases ranging from meningitis to infectious hepatitis to eye infections. Many viral infections are latent, making it difficult to trace their source.

These viruses can cause a wide variety of diseases, such as paralysis, meningitis, respiratory illness, myocarditis, congenital heart anomalies, diarrhea, eye infections, rash, liver disease, and gastroenteritis. Almost all of these viruses also produce inapparent or latent infections. This makes it difficult to recognize them as being waterborne. Documented outbreaks of waterborne viral disease have largely been limited to infectious hepatitis, mainly because of the explosive nature of the outbreaks and the characteristic nature of the disease.

Poliovirus (the cause of polio) is a stable virus and can remain infectious for relatively long times

in water. Infection is primarily by ingestion of contaminated water or food. Waterborne epidemics have been reported. Vaccines could theoretically eliminate polio if the entire world were vaccinated. This is unfeasible, so attention must be paid to the possible introduction of poliovirus from an unvaccinated population.

Poliovirus may be spread by unvaccinated persons via contaminated water; land application sites must still be concerned about its spread.

Coxsackieviruses are responsible for a wide range of diseases. The mechanism of transmission is uncertain, although viruses are often found in feces, which would indicate that oral ingestion may be a causative factor.

Echoviruses induce symptoms ranging from minor respiratory disease to afflictions of the central nervous system. Commonly this type of virus is transmitted orally, although some may infect the respiratory system by inhalation. Again, since these viruses may be excreted with the feces, proper sewage treatment is necessary.

Proper sewage treatment is needed to control echoviruses.

Hepatitis virus is a cause of liver disease only in man. Infectious hepatitis can be spread through the fecal-oral route. These viruses are quite stable though various chemical processes have been used to destroy them.

Infectious hepatitis occurs in two forms, Types A and B, of which only Type A is transmitted by the fecal-oral route. Although convalescence may be prolonged, recovery is complete in over 85% of the cases. The fatality rate in the United States is between 1.5 and 2% out of an incidence rate in 1972 of 30.5/100,000 (Jawetz, et al., 1974). However, it is a major public health problem worldwide. Sudden epidemics resulting from fecal contamination of drinking water or food occur periodically. Consumption of shellfish from sewage-contaminated waters also accounts for outbreaks of hepatitis. The organism responsible for the dis-

Outbreaks of infectious hepatitis have been linked with ingestion of sewage-contaminated foods. It is of utmost importance to control this virus.

ease is quite resistant to heat, acid, and chemical treatment. Because sewage contamination of foods has been linked to outbreaks of the disease, it is of the utmost importance to control the hepatitis virus through proper handling of sewage.

Knowledge of the actual number and concentration of human pathogenic viruses in wastewater is inadequate because sampling and analytical procedures are neither standardized nor adequate. Furthermore, the methodology for detecting and monitoring many of these agents has not yet been developed. This probably accounts for the fact that almost 60% of all documented cases of disease attributable to drinking water in the United States have been reported to be caused by agents as yet not isolated in the laboratory. It appears now that many of the virus sampling difficulties encountered in the past are being overcome, and some researchers are beginning to call for routine viral analysis in areas like treatment plant control. Great difficulties remain in the analytical work necessary to identify and quantify viruses, however, and this procedure is certainly out of range of almost all laboratories as a routine measure. It is important to note that viruses as a group are generally more resistant to environmental stresses than pathogenic bacteria.

Scientific procedures to detect viruses are inadequate, and 60% of all disease cases attributed to drinking water have been caused by agents not identified in laboratories.

Viruses are generally more resistant to environmental stresses than pathogenic bacteria.

Protozoa, Worms Can Cause Disease

Protozoa pathogenic to man and capable of transmission in wastewater are Entamoeba histolytica, the agent of amoebic dysentery; Naegleria gruberi, which may cause fatal meningoencephalitis; and Giardia lamblia, which produces a variety of intestinal symptoms. Waterborne outbreaks of Giardia lamblia have increased in the United States in recent years.

Entamoeba histolytica cannot exist in its active form outside of its host. However, it is capable

of forming cysts which are excreted. These cysts protect the protozoan from adverse environmental conditions outside the host. The cysts may also resist waste treatment processes and are capable of causing disease when ingested with contaminated food or water.

The agent of amoebic dysentery can form cysts which resist treatment and can cause disease when ingested.

The eggs of several intestinal parasitic worms have been found in wastewater and have been shown to be a potential health problem to wastewater treatment plant operators and laborers employed on farms in India and East Germany where wastewater is used for irrigation (Clark, et al., 1976). Modern water treatment methods have proved a very effective barrier against the waterborne spread of disease caused by protozoa and parasitic worms in developed countries.

Modern water treatment in developed countries prevents the waterborne spread of disease from protozoa and parasitic worms.

Various Treatments Reduce Pathogen Levels

The planner or engineer needs to know the number of pathogens in untreated and treated wastewater to evaluate the relative risk of disease transmission associated with land application of wastewater. He also must know the number of pathogens that are necessary to cause an infection in man or other animals.

It is important to know the number of pathogens in untreated wastewater and the infective dose of various pathogens.

Table 6 estimates the relative concentrations of pathogens in untreated wastewater and the relative efficiency of removal by primary and secondary treatment.

TABLE 6. Estimated Concentrations of Selected Wastewater Pathogens[a]

Pathogen	Number of organisms/gal (3.78 L)			
	Untreated wastewater	Primary effluent	Secondary effluent	Disinfection[b]
Salmonella	2.0×10^4	1.0×10^4	5.0×10^2	5×10^{-1}
E. histolytica	1.5×10^1	1.3×10^1	1.2×10^1	1.2×10^{-2}
Helminth ova	2.5×10^2	2.5×10^1	5.0×10^0	5×10^{-3}
Mycobacterium	2.0×10^2	1.0×10^2	1.5×10^1	1.5×10^{-2}
Human enterovirus (poliovirus, etc.)	4.0×10^4[c]	2.0×10^4	2.0×10^3	2×10^2

a. Adapted from Foster and Engelbrecht (1973).

b. Conditions sufficient to yield a 99.9% kill.

c. As high as 4×10^6 per gal (3.78 L) have been reported.

Data on removal efficiency of wastewater treatment methods for many pathogens are inadequate.

Unfortunately, data on the removal efficiency of all wastewater treatment methods for many pathogens are either nonexistent or largely based on laboratory studies by researchers who overestimate the efficiency that can be obtained in actual practice. (Foster, Engelbrecht, 1973).

Figures 3 through 6 show the efficiencies of various forms of conventional treatment for the removal of bacteria, viruses, protozoa and helminths. These figures are summaries of data from a literature review comprising studies by the following authors, all cited in the bibliography: Foster and Engelbrecht, Cody and Tischer, Kabler, Fitzgerald and Rohlick, McKinney, Parsons, CEQ, Wang and Dunlop, Cram, Bryan, Rudolfs et al., and Newton et al. Several species are represented in the graphs for each organism, therefore, the figures show the broadest range of values reported in any category.

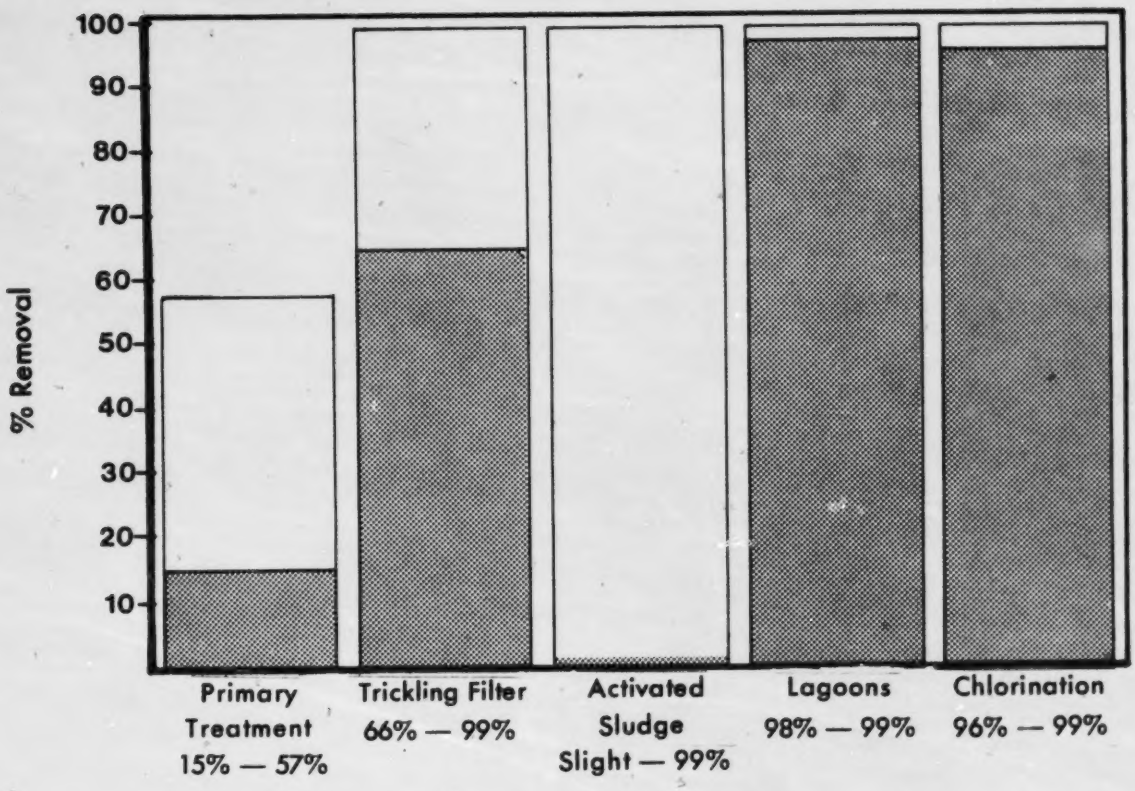


Figure 3
Treatment Processes Differ in their Removal of Bacteria.

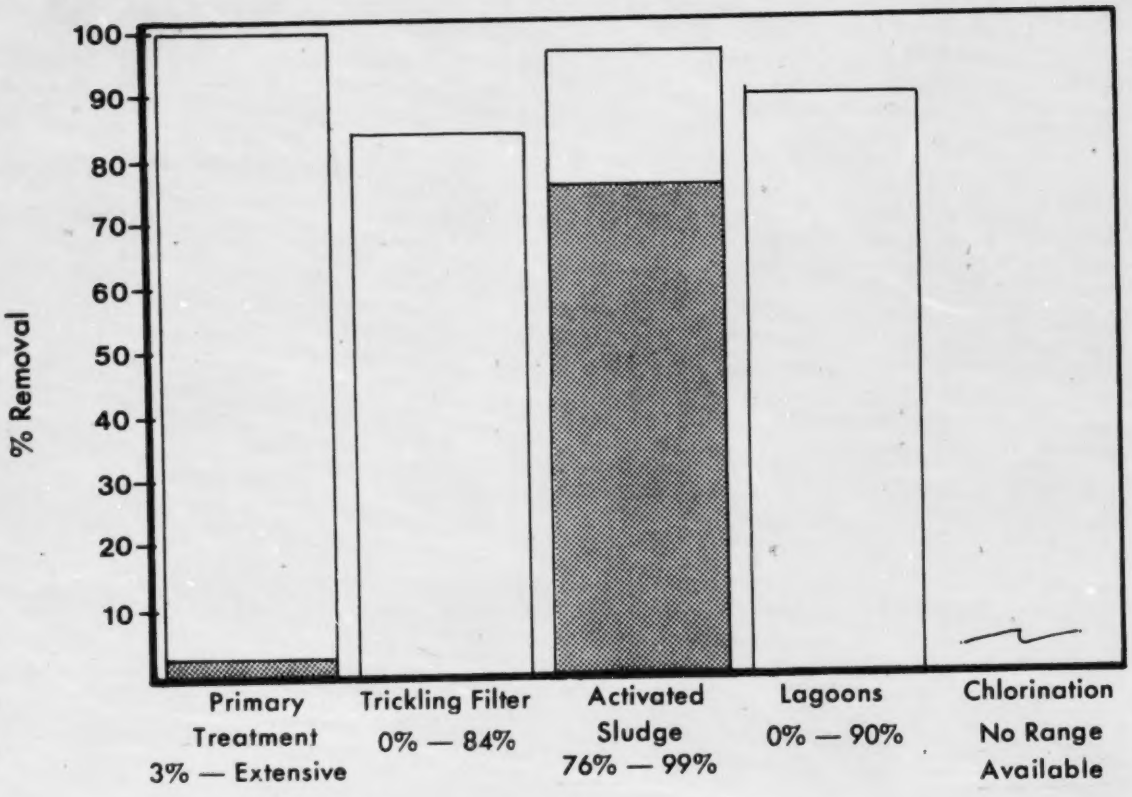


Figure 4
Less Certainty Exists on Virus Removal.

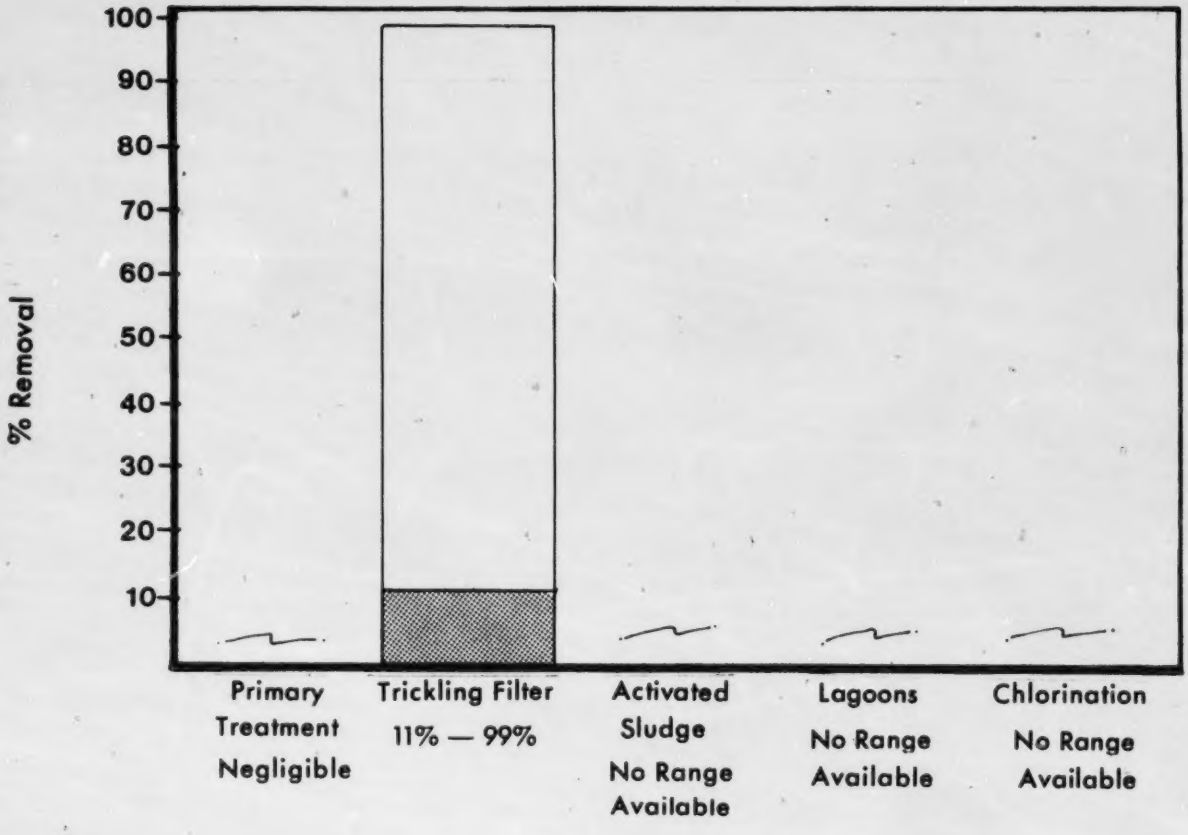


Figure 5
Protozoan Removal Data are Very Scarce.

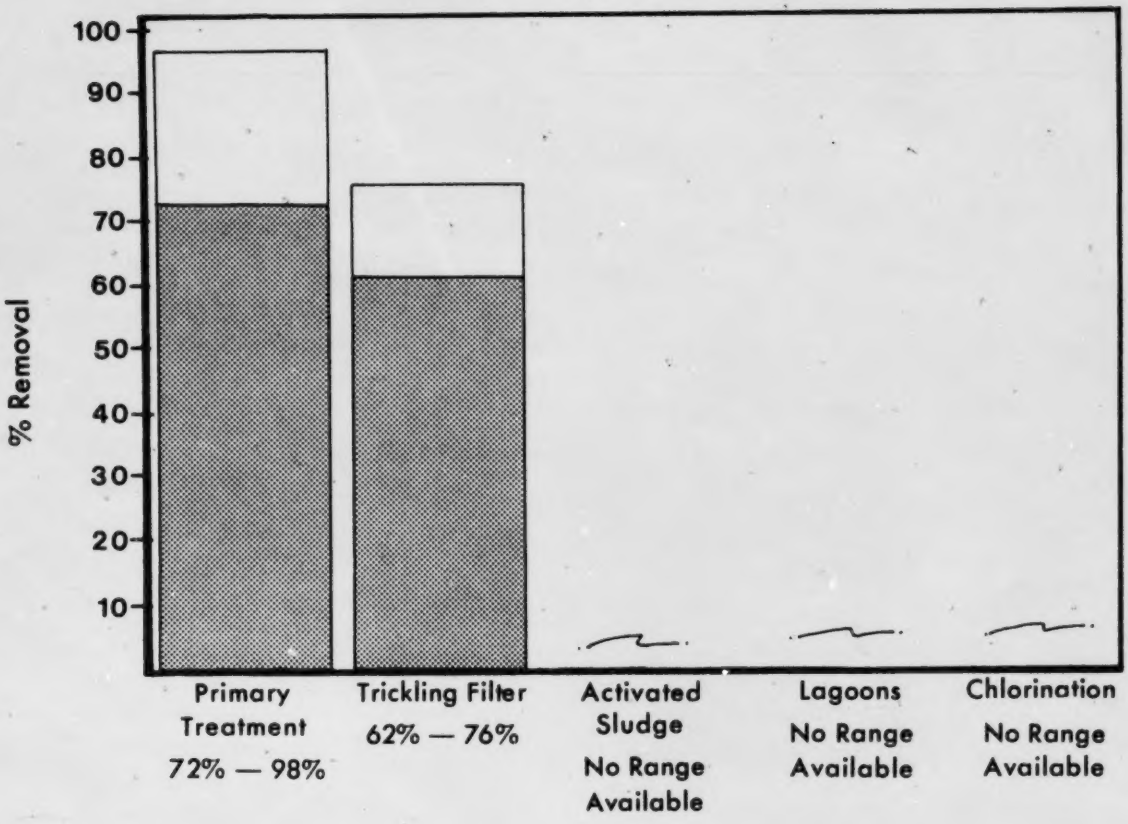


Figure 6
Primary Treatment Appears more Efficient for Helminth Removal

Chlorination Does Not Destroy Pathogens Completely

Chlorination greatly reduces bacterial pathogens but is less effective against cysts and enteric viruses.

Chlorination cannot be relied upon to provide complete destruction of pathogenic bacteria and viruses. It is highly effective in achieving large reductions of bacterial pathogens, but it is much less effective against cysts and enteric viruses. For example, a chlorine dose of 2 mg/ℓ killed 99.9 % of the coliform bacteria in 60 minutes in wastewater, whereas it took a chlorine dose of 20 mg/ℓ to achieve the same kill of poliovirus. (Hoadley and Goyal, 1976). This level of chlorination is not economically feasible and is undesirable due to formation of chloramines and organic complexes. Another factor which complicates transfer of laboratory data obtained with pure viruses to wastewater in the field situation is that polioviruses and other viruses are much more resistant to chlorine if organic matter is present (Trask, et al., 1945). Table 7 describes other factors influencing the effectiveness of chlorination.

High levels of chlorination are undesirable for land treatment because of high cost and unsatisfactory results.

TABLE 7. Several Factors Affect the Efficiency of Chlorine in Destroying Wastewater Pathogens:

- -Increased exposure time increases efficiency
- -Increased concentration of chlorine increases efficiency
- -Decreased organic content increases efficiency
- -Decreased ammonia concentration increases efficiency
- -Increased temperature increases efficiency
- -Decreased pH increases efficiency
- -Increased residual chlorine increases efficiency
- -Decreased suspended solids increase efficiency

Chlorine disinfection works by preventing normal respiration by the organisms. It should be remembered that bacteria can multiply very quickly when environmental conditions become favorable. Thus, a high kill figure may not necessarily mean that no disease threat remains. Effectiveness of bacterial removal should be measured as residual bacteria

A high kill of bacteria by chlorination does not eliminate the threat of bacterial disease.

counts rather than percentage kill.

Infective Doses must be Considered

The planner or engineer must consider the infective dose - the number of organisms necessary to cause disease in man or animals - to evaluate the disease potential of the system. Infective doses for most bacterial and protozoan pathogens are relatively high, but the infective dose for viruses is low.

For instance, ingestion of 10^8 enteropathogenic E. coli or V. Cholera, 10^3 to 10^5 Salmonella, and 10^1 10^2 Shigella organisms are necessary to cause infection in man. (Hoadley and Goyal, 1976) The infective dose of a protozoan, such as E. histolytica, is believed to be as high as 20 cysts (Foster and Engelbrecht, 1973). However, a single virus may produce disease in a human host.

We can conclude that the potential for bacterial disease transmission after disinfection of treated wastewater would appear to be quite small, but the low infective dose of viruses gives importance to even relatively low concentrations of these agents in water.

Because a single virus can cause disease, even relatively low concentrations of viral pathogens in wastewater are a cause for concern.

Aerosol Pathogens Can be Reduced

Aerosols containing bacterial and viral pathogens may be infectious upon inhalation. The body of information at present indicates that at least some potential health effects are related to the production of wastewater aerosols. However, these potential deleterious effects have yet to be fully established.

Bacterial, viral pathogens in aerosols can be inhaled by humans, causing infection.

The following practices are recommended to reduce or eliminate these effects:

-- Creating buffer zones
--Controlling sprinkling operations to minimize the production of fine droplets

--eliminating sprinkling during high winds
--restricting sprinkling to daylight hours
--decreasing nozzle pressure
--aiming the nozzles downward
--planting hedgerows on buffer zones

Aerosols are defined as particles in the size range of 0.01 to 50 μm that are suspended in air. When an airborne water droplet is created, the water evaporates rapidly under average atmospheric conditions, resulting in a nucleus of the originally dissolved solids plus the microorganisms contained in the original droplet. This high rate of evaporation results in the die-off of many of the original organisms, but resistant organisms that remain may persist for a long time.

High rate of evaporation of aerosols results in die-off of many pathogenic organisms.

During sprinkler irrigation about 0.3% aerosolization of the liquid was reported by Sorber, et al., (1975) using fluorescein dye tracers. Some pathogens found in wastewater have a lower infective dose in aerosol form than when ingested directly. The threat of aerosol-borne disease is often discussed. It must be remembered, however, that large concentrations of aerosols are also generated from conventional secondary treatment plants, particularly those employing activated sludge processes or trickling filters. In fact, most of the information available today on wastewater aerosols concerns their generation by conventional wastewater facilities. Airborne coliform bacteria have been recovered at night as far as 0.8 mile (1.3 km) from a large trickling filter plant (Hickey and Reist, 1975).

It may take fewer pathogens to cause infection when inhaled in aerosols than when ingested directly.

There have been no reports of disease transmission from these conventional plants. This fact seems to support the belief that aerosol transmission of disease is not likely from a properly designed and well operated land ap-

Aerosols are generated from conventional treatment plants as well as spray irrigation. There have been no reports of disease transmitted from these plants.

plication system using sprinkler irrigation.

Pathogen Survival Time in Aerosols Depends on Several Factors

How long do pathogenic bacteria and viruses live in aerosols? Under favorable conditions, bacterial aerosols may remain viable for several hours. These bacterial aerosols remain viable and travel further with increased wind velocity and relative humidity, decreased temperature, and darkness. A primary cause of bacterial aerosol destruction seems to be rapid desiccation.

High humidity, increased wind speed, low temperature, darkness enhance survival and travel of bacterial aerosols.

Viruses in aerosols also seem to remain viable for long periods of time. A study by Walker (1970) revealed that polioviruses in aerosols remained active for more than 23 hours when the relative himidity was high. Further study is needed to definitely ascertain the threat of airborne viruses.

Factors that have been found to affect the survival and dispersion of bacteria and viruses in such aerosols are summarized in Table 8.

TABLE 8. Factors that Affect the Survival and Dispersion of Bacteria and Viruses in Wastewater Aerosols

Factor	Remarks
Relative humidity	Bacteria and most enteric viruses survive longer at high relative humidities, such as those occurring during the night. High relative humidity delays droplet evaporation and retards organism die-off.
Wind speed	Low wind speeds reduce biological aerosol transmission.
Sunlight	Sunlight, through ultraviolet radiation, is deleterious to microorganisms. The greatest concentration of biological aerosols from wastewater occurs at night.
Temperature	Increased temperature can also reduce the viability of microbial aerosols mainly by accentuating the effects of relative humidity. Pronounced temperature effects do not appear until a temperature of 80°F (26.7°C) is reached.
Open air	It has been observed that bacteria and viruses are inactivated more rapidly when aerosolized and when the captive aerosols are exposed to the open air than when held in the laboratory.

A model to describe aerosol movement of pathogens has been developed by Sorber, et al. (1974) and was given a preliminary field test in 1975 (Sorber, et al., 1975). The field study enabled these workers to reach six conclusions:

1) Under spray irrigation conditions studied, relatively high concentrations of bacterial aerosols were transmitted for considerable distances.

2) The aerosols carrying the bacteria were in a size range which can be inhaled by humans.

3) Sunlight had little effect on bacterial decay after the bacteria were exposed to initial aerosol shock and desiccation, for the aerosol ages studied.

4) The concentration of organisms at the source and atmospheric stability are the two most important factors influencing downwind aerosol concen-

trations.

5) Low wind speed and darkness are the stable atmospheric conditions which lead to the highest bacterial aerosol concentrations downwind.

6) Effective disinfection was found capable of reducing aerosols to background levels in reasonable distances.

In addition, the authors provided two inferences relating to the decrease of viable particles. The authors concluded that a distance in excess of 1800 meters is required to reduce the concentration of viable particles to within 5 organisms/m^3 air of the background concentration. This figure was extrapolated from the test data, which was collected at distances up to about 150 meters from the spray point. No correlation was attempted between background levels of bacteria and infectious doses for pathogenic organisms which would relate to the desirability of achieving this sort of reduction in atmospheric concentration.

The bacterial populations from the chlorinated wastewater were found to be much less affected by aerosol shock and age than those in the unchlorinated wastewater. That is, although the bacterial concentrations were much less at the source in the chlorinated samples, the percent reduction of viable organisms was such that reasonable levels of atmospheric bacteria could be achieved within relatively short distances by atmospheric die-off without disinfection. The organisms most susceptible to disinfection by chlorine may also be those most easily killed by desiccation in aerosols.

Organisms most susceptible to destruction by chlorine may also be those most easily destroyed by desiccation in aerosols.

Few Statistics are Available on Spread of Aerosols

Another quantitative study was done on the spread of aerosols from land application systems. In this study, Merz (1957 - now out of print) investigated the hazards

In spraying treated wastewater, one investigator found that hazards were limited to direct contact with unevaporated drops.

associated with sprinkling treated wastewater onto a golf course. He concluded that the hazards were limited to direct contact with unevaporated droplets.

Conclusions of other articles and unpublished studies on aerosol viability and drift from sprinkler systems follow. All of these, along with Merz, are referenced in Metcalf and Eddy (1977).

--Reploh and Handloser estimated that a viable aerosol can be carried 1,312 feet downwind by a 16 ft/s (5 m/s) wind. They recommended the planting of hedges as a safety measure. Type of wastewater: untreated

--Bringmann and Trolldenier estimated that coliform organisms can remain viable 1,312 feet downwind from the source under a 23 ft/s (7 m/s) wind under conditions of darkness and 100% humidity. Type of wastewater: settled but not disinfected.

--Sepp found coliform bacteria in aerosols 10 feet downwind in a dense brushy area; up to 200 feet downwind in a sparsely vegetated area. Type of wastewater: ponded and chlorinated secondary effluent

--Shtarkas and Krasilshchikov found bacteria 2,133 feet downwind. Type of wastewater: water from a small stream contaminated with untreated domestic wastewater

--Bausum et al. (1976) found bacterial viruses 2,067 feet from the wetted zone at a sprinkler irrigation site.

Israeli Study Calls for More Epidemiological Research

Katzenelson, et al. (1976) reported the first epidemiological evidence of a disease risk associated with wastewater sprinkler irrigation. In a study of 77 kibbutzim (collective farm settlements) that used wastewater for irrigation and 130 kibbutzim that did not use wastewater for any purpose, the team found that the incidence of disease was 2 to 4 times higher in those settlements that used sewage for spray irrigation. In Israel, domestic

Incidence of sewage-associated disease at Israeli settlements using spray irrigation of wastewater was 2 to 4 times higher than at settlements that did not use wastewater at all, one study reported.

wastewater effluents have been used extensively for agricultural irrigation for more than 20 years, mainly by sprinkler systems. The level of enteric microorganisms in these partially treated nondisinfected oxidation pond effluents (mean detention time of 3 to 7 days) often approaches that of raw domestic sewage.

Diseases that occurred more often included shigellosis, salmonellosis, infectious hepatitis, typhoid fever, and influenza. The incidence of diseases not associated with sewage, such as strep infection and tuberculosis, was not significantly different between the two types of settlements. Neither was there any difference in disease outbreaks during the winter between the two settlements, a time when irrigation is not practiced.

The investigators noted that the pathogens from wastewater might reach the kibbutz populations by an alternate pathway, such as on the bodies and clothes of irrigation workers who live in the community and return from the fields at mealtime and at the end of the day. Indeed, very poor sanitation has been observed at many of the sites, and it is extremely likely that pathogens are being transported directly from sewage in the fields to dining facilities and other communal areas on the clothes of farm workers. The pathway of disease spread from wastewater is not clearly defined in this study. More detailed and controlled epidemiological research is needed on disease transmission from waste treatment sites that use irrigation.

Pathway of disease transmission in this Israeli study is not clear; more epidemiological studies on disease transmission from waste treatment sites are needed.

Bibliography

Arkin, E. W., W. H. Benton, and W. F. Hill. 1971. Enteric viruses in ground and surface water: a review of their occurrence and survival. in Virus and water quality: occurrence and control. 13th Water Quality Conference, 59, University of Illinois. 222 pp.

Alexander, M., et al. 1972. Accumulation of nitrate. Nat'l Academy of Sciences, Washington, D.C. 106 pp.

Anonymous. 1970. "Mercury poisoning leaves tragic mark on N. M. family." The Minneapolis Tribune, 16 August: 14A.

Batey, T., C. Berrgman, and C. Line. 1972. The disposal of copper-enriched pig-manure slurry on grassland. J. Brit. Grassland Soc. 27: 139-143.

Bausum, H. T., S.A. Schaub and C. A. Sorber. 1976. Viral and bacterial aerosols at a wastewater spray irrigation site. In: Abstract of the annual meeting, American Society of Microbiologists. p. 193.

Bernarde, M. A. 1973. Land disposal and sewage effluent: appraisal of health effects of pathogenic organisms. J. Amer. Water Works Ass. 65(6):432-440.

Bryan, F. L. March, 1974. Diseases transmitted by foods contaminated by wastewater. Presented at the Conference on the Use of Wastewater in the Production of Food and Fiber, Oklahoma City, Oklahoma.

Buras, N. 1976. Concentration of Enteric Viruses in Wastewater. Water Resources. 10(4):295-298.

Burge, W. D. July, 1974. Pathogen considerations. in National program staff, factors involved in land application of agricultural and municipal wastes. Agricultural Research Service. Soil, water and air sciences. USDA. Beltsville, Maryland 20705. pp 37-50.

Butler, R. G., C. T. Orlob, and P. H. McGauhey. 1954. Underground Movement of Bacterial and Chemical Pollutants. Jour. AWWA. 46:97-111.

Carlson, G. F., et al. 1968. Virus Inactivation on Clay Particles in Natural Waters. Jour. WPCF. 40(2):R89-R106.

Clark, C. S., et al. 1976. Disease risks of occupational exposure to sewage. J. of the Environ. Eng. Div., Proceedings of the A.S.C.E. 102(EE2):375-388.

Cody, R. M. and R. G. Tischer. 1965. Isolation and frequency of occurrence of Salmonella and Shigella in stabilization ponds. J. Water Pollut. Contr. Fed. 37(10):1399-1403.

Cohen, J., et al. 1971. Epidemiological Aspects of Cholera: El Tor Outbreak in a Non-Epidemic Area. Lancet. 2:86.

Committee on Environmental Quality Management of the Sanitary Engineering Division. 1970. Engineering evaluation of the virus hazard in water. J. Sanitary Eng. Division. A.S.C.E., vol. 96, SAI, pp. 111-161.

Cram, E. B. 1943. The effect of various treatment processes on the survival of helminth ova and protozoan cysts in sewage. Sewage Works J., 15:1119.

Curtis, H. 1968. Biology. Worth Publishers, Inc., New York, N.Y. 854 pp.

Davis, Bernard D., R. Dulbecco, H.M. Eisen, H.S. Ginsberg, W.B. Wood, Jr. 1967. Microbiology. Harper and Row, N.Y. 520 pp.

Drewry, W. A. and R. Eliassen. 1968. Virus Movement in Groundwater. Jour. WPCF. 40(8):R257-R271.

Duboise, S. M., B. E. Moore, and B. P. Sagik. 1976. Poliovirus Survival and Movement in a Sandy Forest Soil. Applied Environmental Microbiology. 31(4):543-546.

Dunlop, S. G. 1968. Survival of pathogens and related disease hazards. in Municipal sewage effluent for irrigation. C. W. Wilson, and F. E. Beckett, (eds.). Louisiana Tech. Alumni Foundation, Tech. Station. Ruston, LA.

Fitzgerald, G. P. and G. A. Rohlich. 1959. An evaluation of stabilization pond literature, cited by Kabler, P., in Removal of pathogenic microorganisms by sewage treatment of processes. Sewage Inc. Wastes 31:12, 1373-1382.

Foster, D. H. and R. S. Engelbrecht. 1973. Microbial hazards of disposing of wastewater on soil in W. E. Sopper and L. T. Kardos, eds. Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State Univ. Press, University Park, PA pp. 247-270.

Gallagher, R. 1969. Diseases that plague modern man. Oceana Publications, Dobbs Ferry, N.Y. 230 pp.

Gerba, C. P., C. Wallis, and J. L. Melnick. 1975. Fate of Wastewater Bacteria and Viruses in Soil. Journal of the Irrigation and Drainage Division, Proceedings of the ASCE. 101(IR3):157-174.

Gilbert, R. G. et al. 1976. Wastewater Renovation and Reuse: Virus Removal by Soil Filtration. Science. 192:1004-1005.

Goldsmid, J., D. Zohar, Y. Argaman, and Y. Kott. June 1972. Effect of Dissolved Salts on the Filtration of Coliform Bacteria in Sand Dunes. (Presented at the 6th International Water Pollution Research Conference).

Hickey, J. L. S. and P. C. Reist. 1975. Health significance of airborne microorganisms from wastewater treatment processes. J. Water Pollut. Contr. Fed. 47(12):2741-2773.

Hickman, Cleveland P. 1966. Integrated principles of Zoology. The C. V. Mosby Company, St. Louis. 965 pp.

Hoadley, A. S. and S. M. Goyal. 1976. Public Health Implications of the Application of Wastewater to Land. In: Land Treatment and Disposal of Municipal and Industrial Wastewater. Sanks, R. L. and T. Asano (eds.) Ann Arbor, Ann Arbor Science. pp. 102-132.

Iwanszuk, J. and W. Dozanska. 1959. Effects of chlorination on the survival of Ascaris suis eggs in sewage. Water Pollut. Abstr., 32:2074.

Jawetz, E., J. L. Melnick, and E. A. Adelberg. 1974. Review of medical microbiology. Lange Medical Publications. Los Altos, CA 528 p.

Jensen, K. A. and K. E. Jensen. 1942. Occurrence of tubercle bacilli in sewage and experiments on sterilization of tubercle bacilli - containing sewage with chlorine. Acta Tuberc. Pnevmol. Scan. 16:217.

Kabler, P. 1959. Removal of pathogenic microorganisms by sewage treatment processes. Sewage Ind. Wastes. 31(12):1373-1382.

Katzenelson, E., I. Borum, and H. I. Shuval. 1976. The risk of communicable disease infection associated with wastewater irrigation in agricultural settlements. Science. 194:944-946.

Kelley, S. and W. W. Sanderson. 1959. The effect of sewage treatment on viruses. Sewage Ind. Wastes. 31(6):683-689.

Kingsbury, J. M. 1964. Poisonous plants of the U.S. and Canada. Hall, NJ. 626 pp.

Kradel, D. C., G. LaMotte, H. Rothenbacher, P. J. Glantz, V. Pidcoe. 1975. Comparison of the occurrence of potentially pathogenic organisms in wild animals ranging over municipal wastewater irrigated and non-irrigated areas. in Wood, G. W., P. J. Glantz, and D. C. Kradel (eds.). 1975 Faunal Response to spray irrigation of chlorinated sewage effluent. Inst. for res. on land and water resources. The Pennsylvania State Univ. Research Publ. #87. 89 pp.

Krishnaswami, S. K. 1971. Health aspects of land disposal of municipal wastewater effluents. Can. J. Public Health. 62:36.

Krone, R. B., G. T. Orlob, and C. Hodgkinson. 1958. Movement of coliform bacteria through porous media. Sewage & Industrial Wastes. 30:1-13.

Krone, R. B. July 1968. The movement of disease producing organisms through soil. (Presented at the Symposium on the Use of Municipal Sewage Effluent for Irrigation. Louisiana Polytechnic Institute, Ruston.)

Kruse, C. W., Y. C. Hsu, A. C. Griffiths, and R. Stringer. 1970. Halogen action of bacteria, viruses, and protozoa. Proc. National Speciality Conf. on Disinfection, 113. A.S.C.E., New York.

Lance, J. C., C. P. Gerba, and J. L. Melnick. 1976. Virus movement in soils columns flooded with secondary sewage effluent. Applied Environmental Microbiology. 32(4):520-526.

Liu, O. C., H. R. Seraichekas, E. W. Akin, D. A. Brashear, E. L. Katy, and W. F. Hill, Jr. 1971. Relative resistance of 20 human viruses to free chlorine in Patomic water. in Virus and water quality, occurrence and control. 13th Water Quality Conf. Univ. of Illinois. 222 pp.

McGauhey, P. H. and R. B. Krone. 1967. Soil mantle as a wastewater treatment system. Sanitary Eng. Res. Laboratory Report No. 67-11. Berkeley, Univ. of California. p. 201.

McKinney, R. E., H. E. Langely, and H. D. Tomlinson. 1959. Survival of Salmonella typhosa during anaerobic digestion. Sewage Ind. Wastes. 30:1469-1477.

Merrell, J. C., Jr. and P. C. Ward. 1968. Virus control at the Santee, Calif. project. J. Amer. Water Works Assoc. 60:145-153.

Metcalf and Eddy, Inc. 1977. Process design manual for land treatment of municipal wastewater. U.S. EPA, U.S. Army Corps of Engineers, U.S. Dept. of Agriculture. EPA 625/1-77-008. EPA Technology Transfer, Washington, D.C.

Meyer, R. C., F. C. Hinds, H. R. Isacson, and T. D. Hinesly. 1971. Porcine enterovirus survival and anaerobic sludge digestion. Proc. Intl. Symposium on Livestock Wastes, 183, A.S.A.E. St. Joseph, Michigan.

Miller, R. H. 1973. Some microbiological aspects of recycling sewage sludges and waste effluents on land in Proc. of a joint conf. on recycling municipal sludges and effluents on land. EPA/USD/Nat'l. Ass. of State Universities and Land Grant Colleges. Champaign, Illinois. July 9-13, pp. 79-90.

Miller, R. H. 1973a. The microbiology of sewage sludge decomposition in soil. Unpublished report. Dept. of Agronomy, The Ohio State University.

Mirzoev, G. G. 1968. Extent of survival of dysentery bacilli at low temperatures and self-disinfection of soil and water in the far north. Hygiene and Sanitation. 31:437-439.

Napolitano, P. J. and D. R. Rowe. 1966. Microbial content of air near sewage treatment plants. Water Sewage Works. 11(12):480-483.

Nelson, N., et al. 1971. Hazards of mercury. Environ. Res. 4(1):1-69. Academic Press, New York.

Newfield, R. D. and E. R. Hermann. 1975. Heavy metal removal by acclimated activated sludge. J. Water Pollut. Contr. Fed. 47(2):310-329.

Newton, W. L., A. J. Bennett, and W. B. Figgatt. 1949. Observations on the effects of various sewage treatment processes upon eggs of Taenia saginata. Amer. J. Hygiene. 49(2):166-175.

New York State Health Commission. 1932. Public Health in New York State. Albany.

Nordberg, G. F. 1974. Health hazards of environmental cadmium pollution. Ambio 3(2):55-66.

Norman, U. H. and P. W. Kablen. 1953. Bacteriological study of irrigated vegetables. Sewage Ind. Wastes. 25(5):605-609.

Parizek, R. R., L. T. Kardos, W. E. Sopper, E. A. Myers, D. E. Davis, M. A. Farrell, and J. B. Nesbitt. 1967. Wastewater renovation and conservation. Penn State Studies No. 23. The Pennsylvania State Univ. University Park, PA. 71 pp.

Parsons, D., C. Brownlee, D. Wetter, A. Maurer, E. Haughton, L. Kornder, M. Slezak. April 1975. Health aspects of sewage effluent irrigation. Pollu. Cont. Branch, British Columbia Water Res. Service, Dept. of Lands, Forests, and Water Res., Parliament Bldgs. Victoria, British Columbia. 75 pp.

Reed, S. C., et al. 1972. Wastewater management by disposal on the land. Special Report 171. Cold Regions Res. & Eng. Lab., Hanover, New Hampshire. 183 pp.

Rudolfs, W., L. L. Falk, and R. A. Ragotzkie. 1950. Literature on the occurrence and survival of enteric, pathogenic, and related organisms in soil, water, sewage, and sludges, and on vegetation: II. Animal parasites. Sewage Ind. Wastes. 22(11):1417-1427.

Rudolfs, W. L., L. L. Falk, and R. A. Ragotzkie. 1951. Contamination of vegetables grown in polluted soil, II. Field and laboratory studies on Entamoeba cysts. Sewage Works J., 23:478.

Schaub, S. A., et al. 1975. Land application of wastewater: The fate of viruses, bacteria, and heavy metals at a rapid infiltration site. TR7504, U.S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, Frederick, MD.

Sorber, C. A. 1973. Protection of public health. Land disposal of municipal effluents and sludges. EPA-902-9-73-001. U.S. Environ. Prot. Agency, New York.

Sorber, C. A., S. A. Schaub, and H. T. Bausum. 1974. An assessment of a potential virus hazard associated with spray irrigation of domestic wastewaters. in J. F. Malina, Jr. and B. P. Sagik. eds. Virus Survival in Water and Wastewater Systems. Center for Res. in Water Resources, University of Texas, Austin.

Sorber, C. A., H. T. Bausum, and S. A. Schaub. 1975. Bacterial aerosols created by spray irrigation of wastewater. in Wastewater resource manual. Sprinkler Irrigation Association, Maryland. Section 1B9:33-43.

Sproul, O. J. 1975. Virus movement into groundwater from septic tank systems. in W. J. Jewell and R. Swan (eds.). Water pollution control in low density areas. Proc. of a rural environmental eng. conf.

Published for the Univ. of Vermont by the Univ. Press of New England, Hanover, N.H.

Tannock, G. W. and J. M. B. Smith. 1971. Studies on the survival of Salmonella typhimurium and S. bovismorbificans on pasture and in water. Aust. Veg. J., 47:557-559.

Taras, M. J., A. E. Greenberg, R. D. Hoak, and M. C. Rand. 1971. Standard methods for the examination of water and wastewater. Amer. Public Health Ass. Washington, D. C. 874 pp.

Taylor, T. J. and M. R. Burrows. 1971. The survival of escherichia coli and Salmonella dublin in slurry on pasture and the infectivity of S. dublin for grazing calves. Brit. Vet. J. 127:536-543.

Trask, J. D., J. L. Melnick, and H. A. Wenner. 1945. Chlorination of human, monkey-adapted, and mouse strains of poliomyelitis virus. American Journal of Hygiene. 41:30-40.

Walker, B. 1970. Viruses respond to environmental exposure. J. Environ. Health. 32(5):532-550.

Wallis, C., M. Henderson, and J. L. Melnick. 1972. Enterovirus concentration on cellulose membranes. Applied Microbiology. 23(3):476-480.

Wang, W. L. and S. G. Dunlop. 1959. Animal parasites in sewage and irrigation water. Sewage Ind. Waste. 26(8):1020-1032.

Weber, W. J., Jr. 1972. Physicochemical processes for water quality control. Wiley-Interscience, N.Y. 640 pp.

Wellings, F. M., A. L. Lewis, and C. W. Mountain. 1974. Virus survival following wastewater spray irrigation of sandy soils. In: Virus survival in water and wastewater systems. Malina, J. F., Jr. and B. P. Sagik (eds.) Austin, Center for Research in Water Resources. pp. 253-260.

Wellings, F. M., A. L. Lewis, and C. W. Mountain. 1975. Pathogenic viruses may thwart land disposal. Water Wastes Eng. March. Vol. 12.

APPENDIX A

VARIOUS GOVERNMENT, AGENCY

GUIDELINES FOR USE OF RECLAIMED WASTEWATER

Guidelines for Wastewater Reuse Vary

To illustrate how two regional governments have responded to the risk of disease transmission from wastewater, we have included the California guidelines for use of reclaimed water and the British Columbia Water Resources Service guidelines on sewage effluent irrigation. The British Columbia Water Resources Service recommends those guidelines established by the World Health Organization.

In the third section of Appendix A are guidelines on wastewater reuse set up by the National Technical Advisory Committee on Water Quality and the World Health Organization.

In the final section are suggestions for crop use of wastewater made by leading researchers in the field.

SUMMARY AND CONCLUSIONS

FROM

HEALTH ASPECTS OF

SEWAGE EFFLUENT IRRIGATION

by

D. Parsons, C. Brownlee, D. Wetter,
A. Maurer, E. Haughton, L. Kornder,
and M. Slezak

April, 1975

British Columbia Water Resources Service

I. SUMMARY AND CONCLUSIONS

1. Treated sewage effluents represent a valuable source of water and nutrients which may be reused to advantage in land irrigation systems. The degree of risk to public health which is associated with effluent irrigation is related to the microbial characteristics of the untreated effluent, the nature of the treatment process, the nature of the crop being irrigated, and the characteristics and location of the irrigated area.

2. In many parts of North America, regulatory agencies have established bacteriological guidelines for agricultural irrigation waters. These guidelines generally allow the use of water having from 1,000 to 10,000 MPN total coliforms/100 ml. Some states have also established guidelines for the agricultural use of sewage effluent.

   In California, for example, primary effluents are considered suitable for the surface or spray irrigation of fodder, fiber, and seed crops, and for the surface irrigation of produce eaten cooked. Effluents used to irrigate dairy pastures and to spray irrigate produce eaten raw should have MPN coliform levels of <23/100 ml.

   Raw or untreated sewage cannot be used for irrigation purposes in Oregon. An adequately disinfected secondary effluent is required for the surface or spray irrigation of alfalfa, grass, timber land, or other fodder crops, but coliform levels of up to 1000/100 mls are permitted.

3. A meeting of experts convened by the World Health Organizations concluded that primary treatment would be sufficient to permit reuse through irrigation of crops not for direct human consumption. Secondary treatment and most probably disinfection and filtration were considered necessary if the effluent were to be used for irrigation of produce for human consumption.

4. A review of literature has shown that outbreaks of communicable disease have been caused by sewage discharges and irrigating produce which is eaten raw with sewage or sewage-polluted water. In all cases, night soil, untreated sewage, or primary sludge has been the source of contamination. Most outbreaks have been associated with the in-

gestion of contaminated water, the consumption of shellfish raised in contaminated water, or the consumption of fruits and vegetables, particularly leafy vegetables, irrigated with sewage or sewage-polluted water and eaten raw.

5. Raw sewage will likely contain each of the intestinal bacteria, viruses, worms, and protozoa that infect the population from which the sewage is derived. The numbers of each microorganism present in the sewage depends upon geographical and cultural factors and upon the extent of sewage dilution during transport.

6. Effluents can be applied to land by subsurface discharge, by flooding, by overland flow, by ridge and furrow irrigation, or by spray irrigation systems. The spray irrigation of effluent will result in the formation of aerosols, and these may contain pathogenic microorganisms. Coliform organisms have been detected within the mist zone of spray irrigation systems.

7. Although there are numerous diseases which may be transmitted through sewage, relatively few are of significance in British Columbia. The incidence of typhoid, paratyphoid, cholera and poliomyelitis is low in British Columbia and throughout North America. Tuberculosis and brucellosis have been eradicated from dairy cattle in Canada. Schistosomiasis, strongyloidiasis, and hookworm infections are diseases of the tropics. The numbers of the pathogenic organisms which cause any of these diseases or infections should therefore be extremely low in sewage effluents in British Columbia. It is unlikely that the use of treated sewage effluents for irrigation will alter the incidence of these diseases in this province.

8. There are some pathogenic microorganisms which can be transmitted via sewage and which may be present in raw sewage in British Columbia. These include the causative agents of salmonellosis, shigellosis, infectious hepatitis, taeniasis, enterobiasis, ascariasis, amoebiasis, and giardiasis.

   Because of the possible presence of these organisms in raw sewage, the use of untreated or of primary treated sewage effluent for irri-

gation purposes constitutes a potential hazard to public health and should not be allowed. Decisions concerning the degree of treatment required before irrigation, system design, buffer zones, and site or crop selection should be made in order to protect the public from these or similar organisms.

9. Primary treatment will remove many of the ova of parasites from raw sewage, but few of the bacteria or viruses. Trickling filters will remove an additional 60% to 70% of the parasite ova and 70% to 90% of pathogenic bacteria, but very few viruses. Slow sand filters, however, can provide virtually complete removal of cysts and ova and greatly reduce viral concentrations.

   Activated sludge systems remove more than 90% of the bacteria and viruses remaining after primary treatment. Aeration has little effect on parasites, but settling during treatment in an activated sludge system should significantly reduce the numbers of parasites present in the effluent.

   Greater than 90% removal of bacteria and viruses is possible with lagoons or stabilization ponds which provide several months retention. Settling during storage in such ponds should also remove the ova and cysts of intestinal parasites. Storage for one month or longer also exceeds the normal life span of many pathogens or parasites.

   Effluent chlorination has little effect on parasite ova and amoeba cysts. 95% to 99+% removal of most bacteria from secondary effluents can be obtained through chlorination if a residual of 1 mg/ℓ is maintained for one hour. Such chlorination of highly clarified effluents may also provide freedom from viruses.

10. There is no single sewage treatment process which will remove all pathogenic microorganisms. Through combinations of treatment processes however, it is possible to produce effluents from which all, or almost all, of each pathogen group has been removed. In order to produce an effluent suitable for irrigation of a wide variety of crops and landscapes, it will probably be necessary to combine an aerobic, biological treatment process with clarification (through settling or filtration), disinfection, and storage.

Detailed recommendations concerning effluent treatment and irrigation for specific purposes are presented in the following chapter.

TABLE 1

TREATMENT PROCESSES SUGGESTED BY THE WORLD HEALTH ORGANIZATION FOR WASTEWATER REUSE

	IRRIGATION			RECREATION	
	Crops not for direct human consumption	Crops eaten cooked; fish culture	Crops eaten raw	No contact	Contact
Health criteria (see below for explantion of symbols)	1 + 4	2 + 4 or 3 + 4	3 + 4	2	3 + 5
Primary treatment	●●●	●●●	●●●	●●●	●●●
Secondary treatment		●●●	●●●	●●●	●●●
Sand filtration or equivalent polishing methods		●	●		●●●
Disinfection		●	●●●	●	●●●

Health criteria:

1 Freedom from gross solids; significant removal of parasite eggs.

2 As 1, plus significant removal of bacteria.

3 Not more than 100 coliform organisms per 100 ml in 80% of samples.

4 No chemicals that lead to undesirable residues in crops or fish.

5 No chemicals that lead to irrigation of mucous membranes and skin.

In order to meet the given health criteria, processes marked ●●● will be essential. In addition, one or more processes marked ●● will also be essential, and further processes marked ● may sometimes be required.

STATE OF CALIFORNIA

DEPARTMENT OF HEALTH

GUIDELINES FOR USE OF RECLAIMED WATER

Berkeley, CA 1974

STATE OF CALIFORNIA DEPARTMENT OF HEALTH

GUIDELINES FOR USE OF RECLAIMED WATER FOR
SPRAY IRRIGATION OF CROPS

1. Reclaimed water shall meet the Regional Water Quality Control Board requirements and the quality requirements established by the State of California Department of Health for health protection.

2. The discharge shall be confined to the area designated and approved for disposal and reuse. Irrigation should be controlled to minimize ponding of wastewater and runoff should be contained and properly disposed.

3. Maximum attainable separation of reclaimed water lines and domestic water lines shall be practiced. Domestic and reclaimed water transmission and distribution mains shall conform to the "Separation and Construction Criteria" (see attached).
   a. The use area facilities must comply with the "Regulations Relating to Cross-Connections," Title 17, Chapter V, Section 7583-7622, inclusive, California Administrative Code.
   b. Plans and specifications of the existing and proposed reclaimed water system and domestic water system shall be submitted to State and/or local health agencies for review and approval.
4. All reclaimed water valves and outlets should be appropriately tagged to warn the public that the water is not safe for drinking or direct contact.

5. All piping, valves, and outlets should be color-coded or otherwise marked to differentiate reclaimed water from domestic or other water.
   a. Where feasible, differential piping materials should be used to facilitate water system identification.

6. All reclaimed water valves and outlets should be of a type that can only be operated by authorized personnel.

7. Adequate means of notification shall be provided to inform the public that reclaimed water is being used. Conspicuous warning signs with

proper wording of sufficient size to be clearly read shall be posted at adequate intervals around the use area.

8. Irrigation should be done so as to prevent or minimize contact by the public with the sprayed material and precautions should be taken to insure that reclaimed water will not be sprayed on walkways, passing vehicles, buildings, domestic water facilities, or areas not under control of the user.
   a. The irrigated areas should be fenced where primary effluent is used.
   b. Windblown spray from the irrigation area should not reach areas accessible to the public.
   c. Irrigated areas must be kept completely separated from domestic water wells and reservoirs. A minimum of 500 feet should be provided.
9. Adequate measures should be taken to prevent the breeding of flies, mosquitoes and other vectors of public health significance during the process of reuse.
10. Operation of the use area facilities should not create odors, slimes, or unsightly deposits of sewage origin.
11. Adequate time should be provided between the last irrigation and harvesting to allow the crops and soil to dry.
    a. Animals, especially milking animals, should not be allowed to graze on land irrigated with reclaimed water until it is thoroughly dry.
12. There should be no subsequent planting of produce on lands irrigated with primary effluent.

GUIDELINES FOR USE OF RECLAIMED WATER FOR

SURFACE IRRIGATION OF CROPS

1. Reclaimed water shall meet the Regional Water Quality Control Board requirements and the quality requirements established by the State of California Department of Health for health protection.

2. The discharge shall be confined to the area designated and approved for disposal and reuse. Irrigation should be controlled to minimize ponding of wastewater and runoff should be contained and properly disposed.

3. Maximum attainable separation of reclaimed water lines and domestic water lines shall be practiced. Domestic and reclaimed water transmission and distribution mains shall conform to the "Separation and Construction Criteria" (see attached).
   a. The use area facilities must comply with the "Regulations Relating to Cross-Connections," Title 17, Chapter V, Sections 7583-7622, inclusive, California Administrative Code.
   b. Plans and specifications of the existing and proposed reclaimed water system and domestic water system shall be submitted to State and/or local health agencies for review and approval.

4. All reclaimed water valves and outlets should be appropriately tagged to warn the public that the water is not safe for drinking or direct contact.

5. All piping, valves, and outlets should be color-coded or otherwise marked to differentiate reclaimed water from domestic or other water.
   a. Where feasible, differential piping materials should be used to facilitate water system identification.

6. All reclaimed water valves and outlets should be of a type that can only be operated by authorized personnel.

7. Adequate means of notification shall be provided to inform the public that reclaimed water is being used. Conspicuous warning signs with proper wording of sufficient size to be clearly read shall be posted at adequate intervals around the use area.

8. The public shall be effectively excluded from contact with the reclaimed water used for irrigation.
   a. The irrigated areas should be fenced where primary effluent is used.
   b. Irrigated areas must be kept completely separated from domestic water wells and reservoirs. A minimum of 500 feet should be provided.

9. Adequate measures should be taken to prevent the breeding of flies, mosquitoes and other vectors of public health significance during the process of reuse.

10. Operation of the use area facilities should not create odors, slimes, or unsightly deposits of sewage origin.

11. Adequate time should be provided between the last irrigation and harvesting to allow the crops and soil to dry.
   a. Animals, especially milking animals, should not be allowed to graze on land irrigated with reclaimed water until it is thoroughly dry.

12. There should be no subsequent planting of produce on lands irrigated with primary effluent.

13. Adequate measures shall be taken to prevent any direct contact between the edible portion of the crops and the reclaimed water.

STATE OF CALIFORNIA DEPARTMENT OF HEALTH

GUIDELINES FOR USE OF RECLAIMED WATER FOR
LANDSCAPE IRRIGATION

1. Reclaimed water shall meet the Regional Water Quality Control Board requirements and the quality requirements established by the State of California Department of Health for health protection.

2. The discharge shall be confined to the area designated and approved for disposal and reuse. Irrigation should be controlled to minimize ponding of wastewater and runoff should be contained and properly disposed.

3. Maximum attainable separation of reclaimed water lines and domestic water lines shall be practiced. Domestic and reclaimed water transmission and distribution mains shall conform to the "Separation and Construction Criteria" (see attached).
   a. The use area facilities must comply with the "Regulations Relating to Cross-Connections," Title 17, Chapter V, Sections 7583-7622, inclusive, California Administrative Code.
   b. Plans and specifications of the existing and proposed reclaimed water system and domestic water system shall be submitted to State and/or local health agencies for review and approval.

4. All reclaimed water valves, outlets and/or sprinkler heads should be appropriately tagged to warn the public that the water is not safe for drinking or direct contact.

5. All piping, valves, and outlets should be color-coded or otherwise marked to differentiate reclaimed water from domestic or other water.
   a. Where feasible, differential piping materials should be used to facilitate water system identification.

6. All reclaimed water valves, outlets, and sprinkler heads should be of a type that can only be operated by authorized personnel.
   a. Where hose bibbs are present on domestic and reclaimed water lines, differential sizes should be established to preclude the interchange of hoses.

7. Adequate means of notification shall be provided to inform the public that reclaimed water is being used. Such notification should include the posting of conspicuous warning signs with proper wording of sufficient size to be clearly read. At golf courses, notices should also be printed on score cards and at all water hazards containing reclaimed water.
8. Tank trucks used for carrying or spraying reclaimed water should be appropriately identified to indicate such.

9. Irrigation should be done so as to prevent or minimize contact by the public with the sprayed material and precautions should be taken to insure that reclaimed water will not be sprayed on walkways, passing vehicles, buildings, picnic tables, domestic water facilities, or areas not under control of the user.
   a. Irrigation should be practiced during periods when the grounds will have maximum opportunity to dry before use by the public unless provisions are made to exclude the public from areas during and after spraying with reclaimed water.
   b. Windblown spray from the irrigation area should not reach areas accessible to the public.
   c. Irrigated areas must be kept completely separated from domestic water wells and reservoirs. A minimum of 500 feet should be provided.
   d. Drinking water fountains should be protected from direct or windblown reclaimed water spray.
10. Adequate measures should be taken to prevent the breeding of flies, mosquitoes and other vectors of public health significance during the process of reuse.

11. Operation of the use area facilities should not create odors, slimes, or unsightly deposits of sewage origin in places accessible to the public.

STATE OF CALIFORNIA DEPARTMENT OF HEALTH

GUIDELINES FOR USE OF RECLAIMED WATER FOR IMPOUNDMENTS

1. Reclaimed water shall meet the Regional Water Quality Control Board requirements and the quality requirements established by the State of California Department of Health for health protection.

2. The discharge shall be confined to the area designated and approved for disposal and reuse. Runoff should be contained and properly disposed.

3. Maximum attainable separation of reclaimed water lines and domestic water lines shall be practiced. Domestic and reclaimed water transmission and distribution mains shall conform to the "Separation and Construction Criteria" (see attached).
   a. The use area facilities must comply with the "Regulations Relating to Cross-Connections," Title 17, Chapter V, Sections 7583-7622, inclusive, California Administrative Code.
   b. Plans and specifications of the existing and proposed reclaimed water system and domestic water system shall be submitted to State and/or local health agencies for review and approval.

4. At restricted recreational impoundments and landscape impoundments all valves and outlets should be appropriately tagged to warn the public that the water is not safe for drinking or bathing.

5. At non-restricted recreational impoundments all valves and outlets should be appropriately tagged to warn the public that the water is reclaimed from sewage and is not safe for drinking.

6. All piping, valves, and outlets should be color-coded or otherwise marked to differentiate reclaimed water from domestic or other water.
   a. Where feasible, differential piping materials should be used to facilitate water system identification.

7. All reclaimed water valves and outlets should be of a type that can only be operated by authorized personnel.

8. Adequate means of notification shall be provided to inform the public that reclaimed water is being used. Such notification should include

the posting of conspicuous warning signs with proper wording of sufficient size to be clearly read.

9. Adequate measures shall be taken to prevent body-contact activities, such as wading or swimming, at restricted recreational impoundments containing reclaimed water.

10. Adequate measures shall be taken to prevent direct public contact with reclaimed water at landscape impoundments.

11. Restricted and non-restricted recreational impoundments shall be maintained under the continuous supervision of qualified personnel during periods of use.

12. Impoundments containing reclaimed water must be kept completely separated from domestic water wells and reservoirs. A minimum of 500 feet should be provided.

13. Adequate measures should be taken to prevent the breeding of flies, mosquitoes and other vectors of public health significance during the process of reuse.

14. Operation of the use area facilities should not create odors, slimes, or unsightly deposits of sewage origin in places accessible to the public.

STATE OF CALIFORNIA DEPARTMENT OF HEALTH

GUIDELINES FOR WORKER PROTECTION
AT WATER RECLAMATION USE AREAS

1. Employees should be made aware of the potential health hazards involved with contact or ingestion of reclaimed water.

2. Employees should be subjected to periodic medical examinations for intestinal diseases and to adequate immunization shots.

3. Adequate first aid kits should be available on location, and all cuts and abrasions should be treated promptly to prevent infection. A doctor should be consulted where infection is likely.

4. Precautionary measures should be taken to minimize direct contact of employees with reclaimed water.
   a. Employees should not be subjected to reclaimed water sprays.
   b. For work involving more than a casual contact with reclaimed water, employees should be provided with protective clothing.
   c. At crop irrigation sites, the crops and soil should be allowed to dry before harvesting by employees.

5. Provisions should be made for a supply of safe drinking water for employees. Where bottled water is used for drinking purposes, the water should be in contamination-proof containers and protected from contact with reclaimed water or dust.
   a. The water should be of a source approved by the local health authority.

6. Toilet and washing facilities should be provided.

7. Precautions should be taken to avoid contamination of food taken to areas irrigated with reclaimed water, and food should not be taken to areas still wet with reclaimed water.

8. Adequate means of notification shall be provided to inform the employees that reclaimed water is being used. Such notification should include the posting of conspicuous warning signs with proper wording of sufficient size to be clearly read.

a. In some locations, especially at crop irrigation use areas, it is advisable to have the signs in Spanish as well as English.

9. All reclaimed water valves, outlets, and/or sprinkler heads should be appropriately tagged to warn employees that the water is not safe for drinking or direct contact (direct contact is allowed at non-restricted recreational impoundments).

10. All piping, valves and outlets should be color-coded or otherwise marked to differentiate reclaimed water from domestic or other water.
    a. Where feasible, differential piping materials should be used to facilitate water system identification.

11. All reclaimed water valves, outlets and sprinkler heads should be of a type that can only be operated by authorized personnel.
    a. Where hose bibbs are present on domestic and reclaimed water lines, differential sizes should be established to preclude the interchange of hoses.

SEPARATION AND CONSTRUCTION CRITERIA

DOMESTIC AND RECLAIMED WASTEWATER TRANSMISSION AND DISTRIBUTION MAINS

Basic Separation		Water Main Involved		RECLAIMED WASTEWATER MAIN CONSTRUCTION MINIMUM SEPARATION IF BASIC SEPARATION IS NOT FEASIBLE		
Parallel Construction	Perpendicular Construction	Reclaimed Wastewater	Domestic Water	Parallel Construction	Perpendicular Construction Reclaimed wastewater main above domestic water main	Perpendicular Construction Reclaimed wastewater main below domestic water main Clearance less than three (3) feet
25'(a)	3'(b)	Pressure	Gravity(c)	No Exception	Minimum pipe class 2 x wwp; Steel casing 25' both sides of crossings	Minimum pipe class 2 x wwp; Steel casing 25' both sides of crossing
25'	3'	Gravity	Gravity	VCP,AC,CIP, or equal, class 150; 15' minimun separation; Mechanical compression joints	Steel casing 25' both sides of crossing	VCP, AC, CIP, or equal, class 150; Mechanical compression joints 25' both sides of crossing
10'	3'	Pressure	Pressure	Minimum pipe class 2 x wwp; 4' minimum separation; no common trench	Minimum pipe class 2 x wwp; Mechanical compression joints 4' both sides of crossing	Minimum pipe class 2 x wwp; Mechanical compression joints 4' both sides of crossing
10'	3'	Gravity	Pressure	VCP; Mechanical compression joints 4' minimum separation	Concrete encasement or steel casing 4' both sides of crossing	VCP, AC, CIP; Mechanical compression joints 4' both sides of crossing

(a) All distances measured from pipeline O.D.
(b) Domestic water main 3' above reclaimed wastewater main.
(c) Less than 5 psi.

RECOMMENDATIONS FROM NATIONAL TECHNICAL

ADVISORY COMMITTEE ON WATER QUALITY

Federal Water Pollution Control Administration, 1968

For waters intended for agricultural use, the monthly average coliform bacteria counts should not exceed 5,000/100 mℓ and the fecal coliform concentration should not exceed 1,000/100 mℓ.

For recreational water, the coliforms should not exceed 1,000/100 mℓ.

For drinking water, the coliforms should not exceed 1/100 mℓ.

LIMITATIONS ON USING WASTEWATER ON AGRICULTURAL CROPS

A SUMMARY OF RELEVANT RESEARCH

Limitations on crop use put forth by Rudolfs, Frank, and Ragotzkie (1950); Krishnaswami (1971); and Geldreich and Bordner (1971) can be summarized as follows:

1. Crops that are eaten after they are cooked, or industrial crops that are eaten after satisfactory processing, may be irrigated with treated wastewater.
2. Oxidized and disinfected wastewater effluent may be used to irrigate fruit and vegetable crops. Vegetables should not be sprinkler irrigated for 4 weeks prior to harvest. Similarly, application on pasture and hay should stop 2 weeks before pasturing or harvesting. (This provides a drying period for farm equipment access.)
3. Reclaimed water used for the surface or spray irrigation of fodder, fiber, and seed crops shall have a level of quality no less than that of primary effluent.

ACKNOWLEDGEMENTS

The development of this program and the preparation of the modules resulted from the collaboration of many individuals in the College of Agriculture and Life Sciences, a statutory unit of the State University at Cornell University, and others. The primary faculty and staff associated with the project were:

PROFESSIONAL STAFF

W. W. Clarkson, Research Associate	Agricultural Engineering
G. S. Friedman, Research Associate	Education
A. C. Plescia, Production Coordinator	Agricultural Engineering

PRINCIPAL FACULTY PARTICIPANTS

W. J. Jewell, Agricultural Engineering	Principal Faculty Advisor
R. C. Loehr, Environmental Studies Program	Project Coordinator
J. D. Novak, Education	Principal Faculty Advisor
E. L. Stone, Agronomy	Principal Faculty Advisor

This program was supported in part by grant T-900500 from the Academic Training Section, U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers.

The current modules are based on modules developed during the initial phase of this project (1974-1976). Other personnel involved with writing or editing initial modules of the program included:

G. A. Garrigan, Education
S. D. Klausner, Agronomy
C. E. Morris, Education
D. F. Smith, Agricultural Engineering
J. E. Stone, Agronomy

M. M. Bogin edited copy and contributed to written and audio-tutorial modules. S. M. Dabney was the primary author of the Crop Selection and Non-crop and Forest Systems modules.

J.K. Krizek, A.L. Liebermann and R.H. Nagell contributed art work and graphic design. L.A. Martin, A.C. Plescia, B.C. Littlefair and others provided secretarial assistance. D.P. Willmot prepared and processed audio-tutorial materials. Audio-tutorial program was narrated by K. Marash.

Other faculty assistance was provided by W.H. Allaway, D.R. Bouldin, D.J. Lathwell, G.W. Olson, and P.J. Zwerman. Technical assistance of various kinds was provided by R. Batkin, S. Haeni, W. Messner, D. Payne, D. Way, G. MacCaskill, and D. Krizek. Thanks are also due to many other members of the Cornell community who shared time, ideas, and materials.

Personnel of the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, N.H. and Office of the Chief of Engineers in Washington, D.C. reviewed the written and audio-tutorial modules. The audio-tutorial modules were also reviewed at the National Training and Operational Technological Center of the Environmental Protection Agency, Cincinnati, Ohio.

State environmental regulatory agencies provided land application guidelines. Many other individuals, companies, and federal agencies provided technical information, comments, and visual materials. Their generosity has made a major contribution to the program.